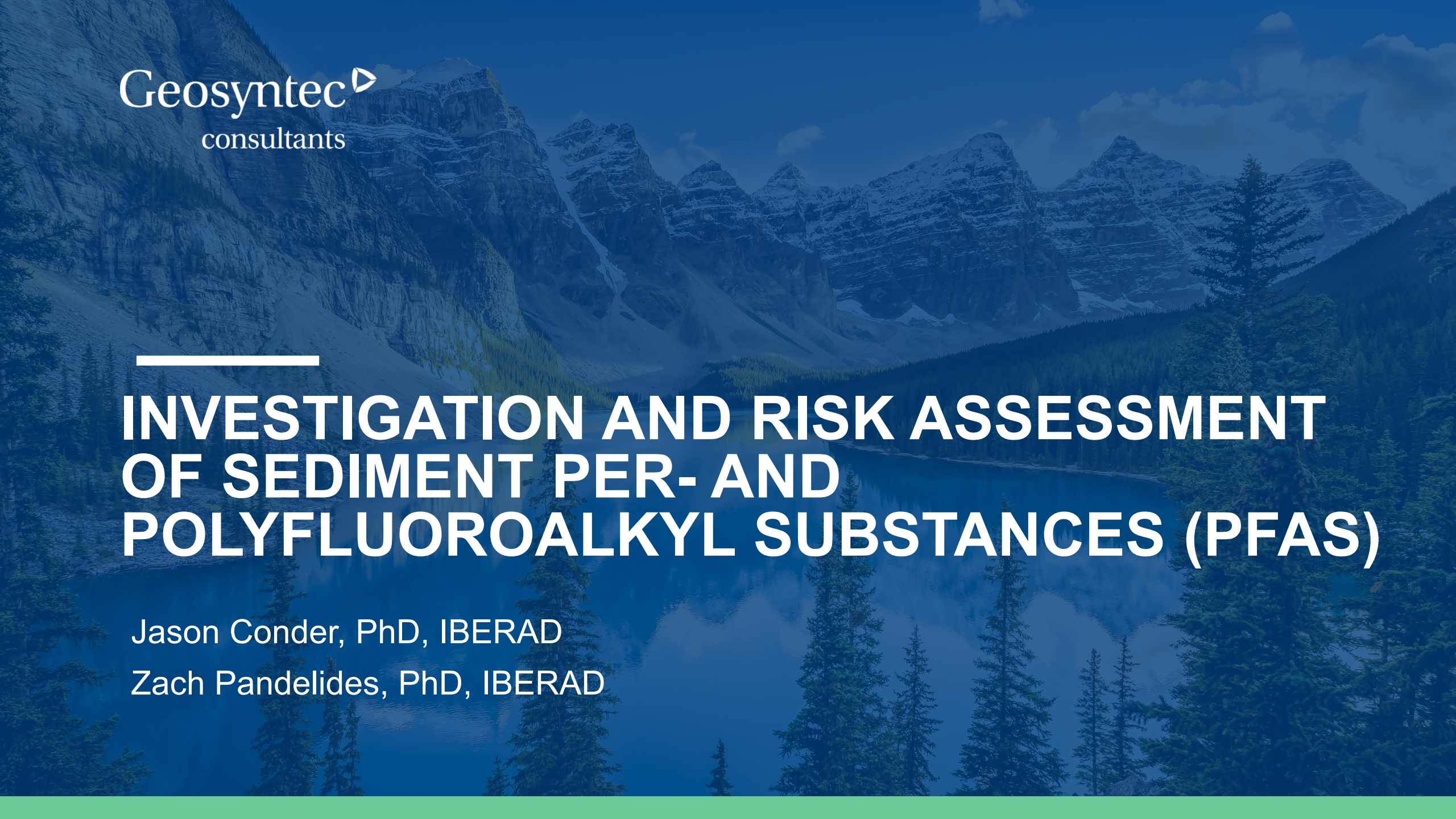


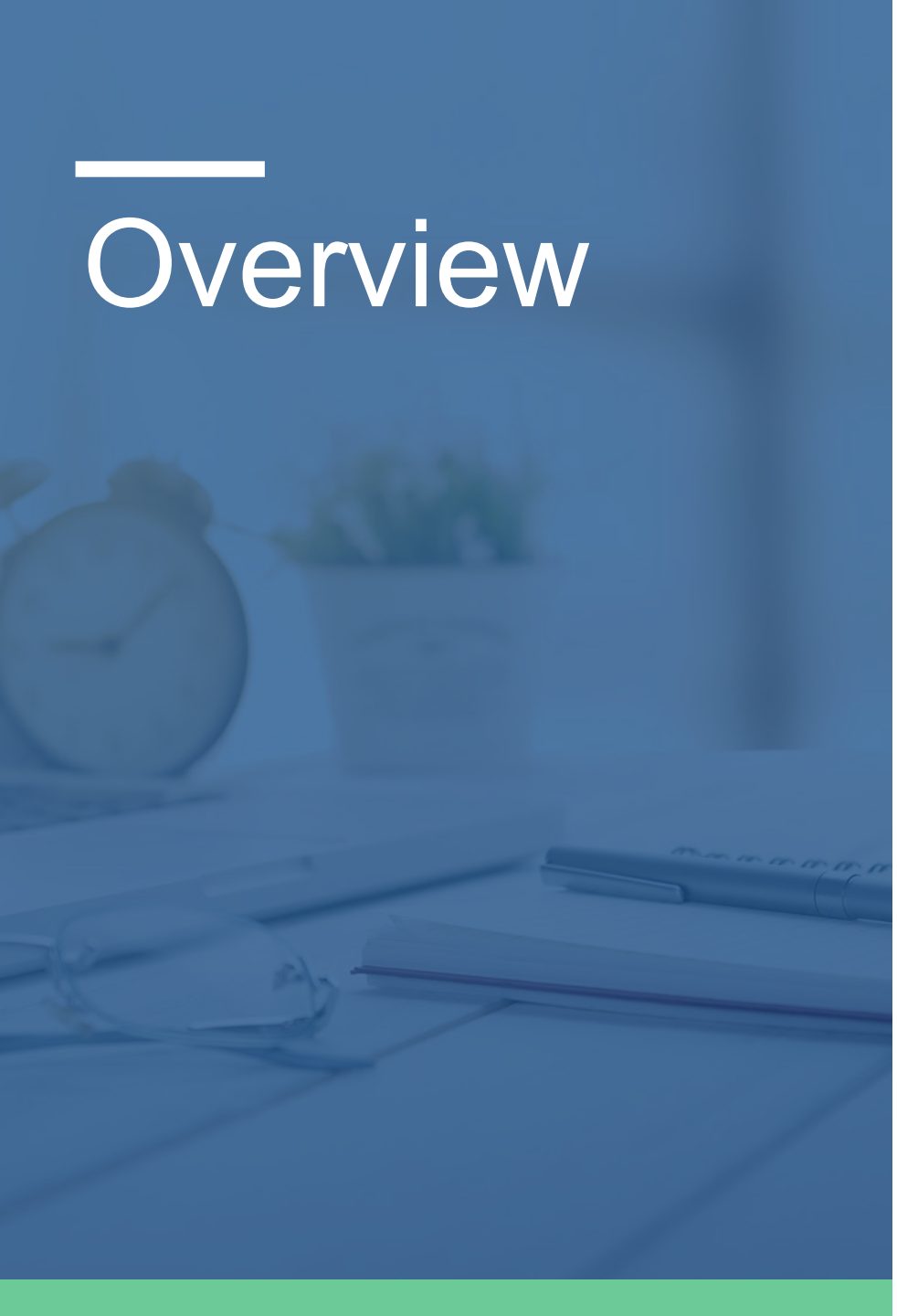
Geosyntec consultants

INVESTIGATION AND RISK ASSESSMENT OF SEDIMENT PER- AND POLYFLUOROALKYL SUBSTANCES (PFAS)

Jason Conder, PhD, IBERAD

Zach Pandelides, PhD, IBERAD

Overview



Overview of PFAS in Sediment

- Characteristics, Toxicity, Nature and Extent

Occurrence in Pacific Northwest

Site-Specific Risk Assessment

Ecotoxicity and Bioaccumulation

Summary/Closing Statements

PFAS in Sediment

Characteristics

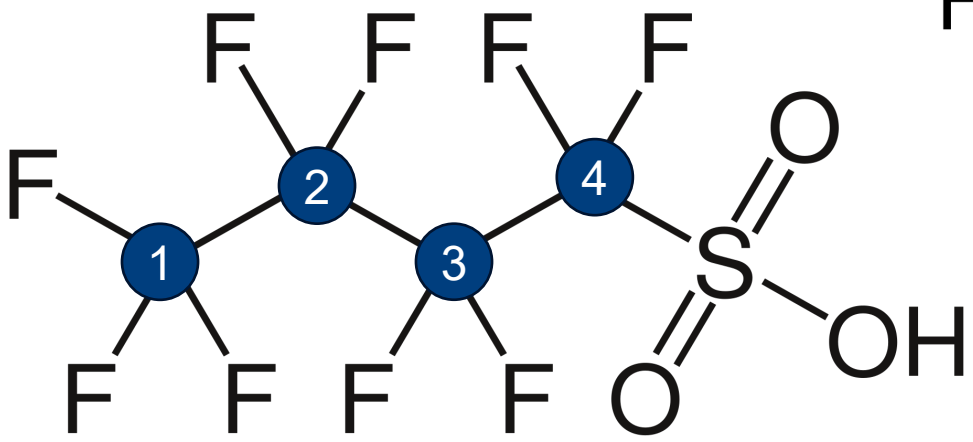
- Persistent (or transform to persistent PFAS)
- Moderately sorptive to organic carbon, yet somewhat soluble in water
- Can bioaccumulate to detectable levels in aquatic life and wildlife

Nature and extent

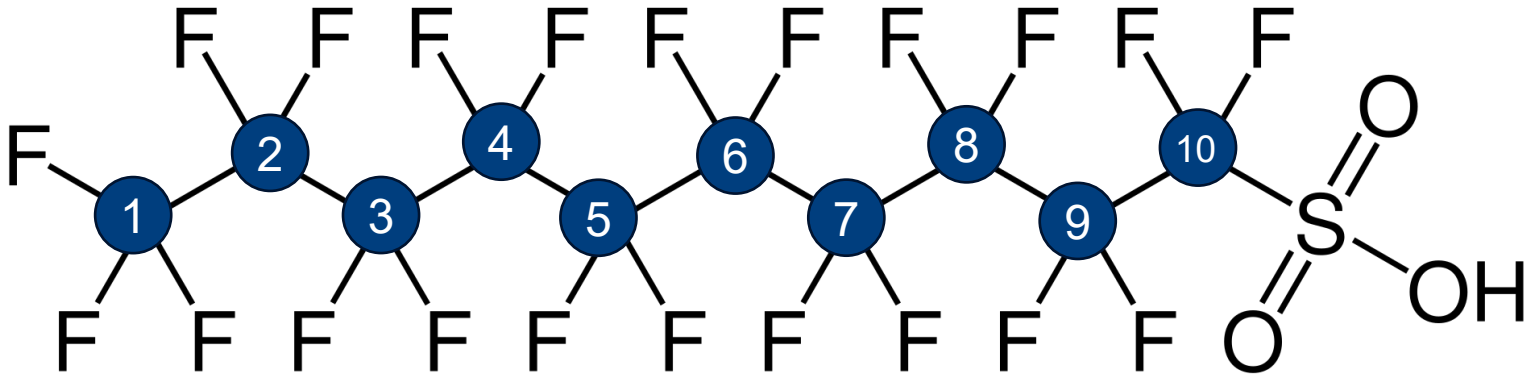
- Detected in sediment and aquatic life (everywhere)
  - Measured concentrations of some PFAS in aquatic biota have exceeded some risk-based thresholds
- Benthic biota (worms) and benthic fish often exhibit the highest tissue concentrations – for some PFAS, sediment is a source

Perfluorinated Carbon Chain Length

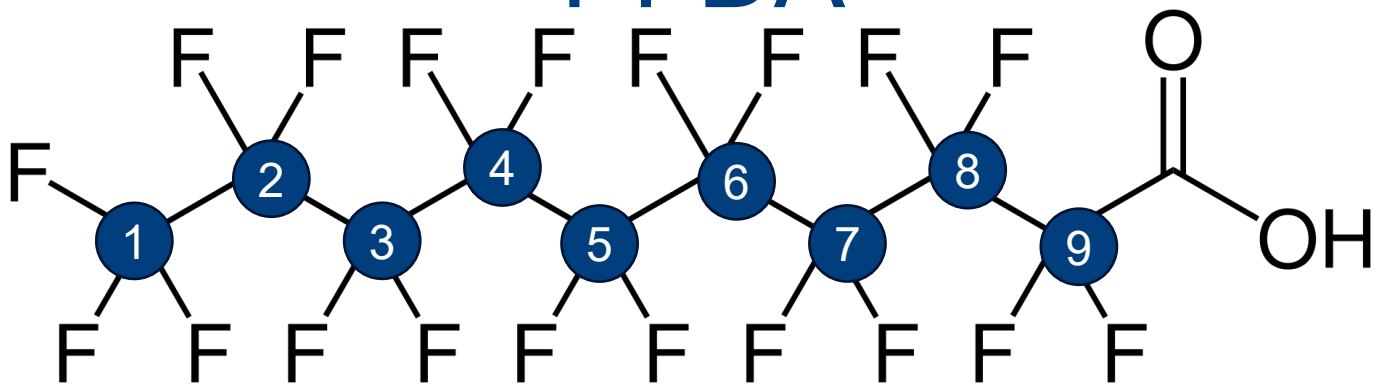
PFBS



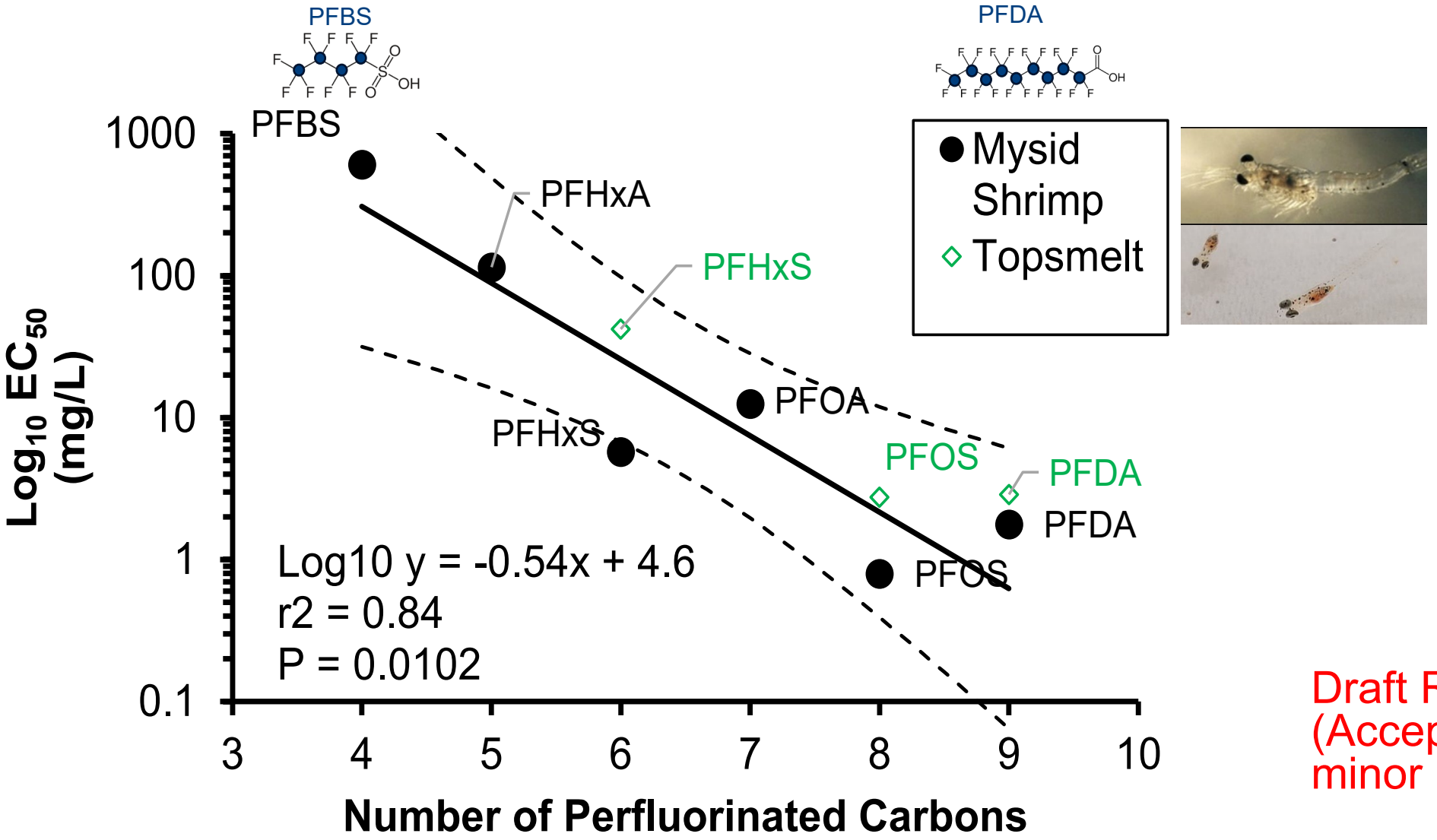
PFDS



PFDA



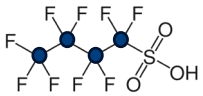
Toxicity Correlates With Chain Length

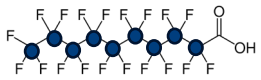


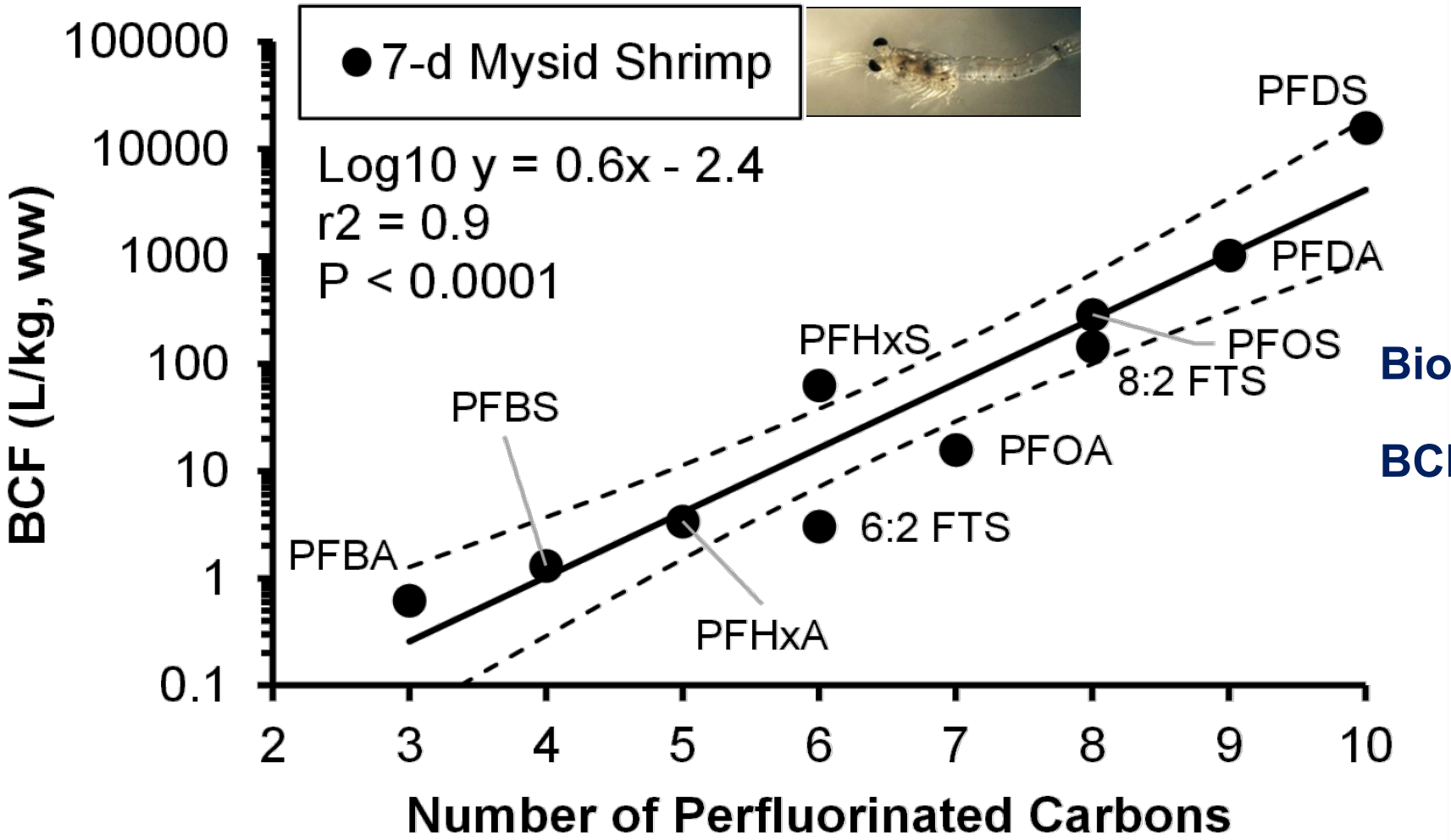
Draft Results
(Accepted pending minor revisions)

Note: The data and research presented on this slide are external grant funded research by Geosyntec and their collaborators

Uptake Correlates With Chain Length







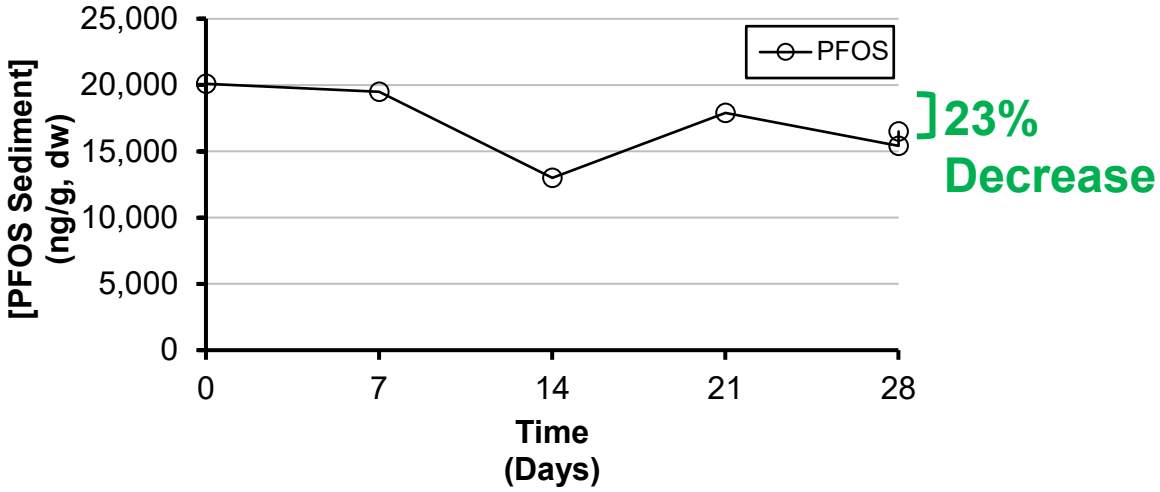
Bioconcentration factor (BCF)

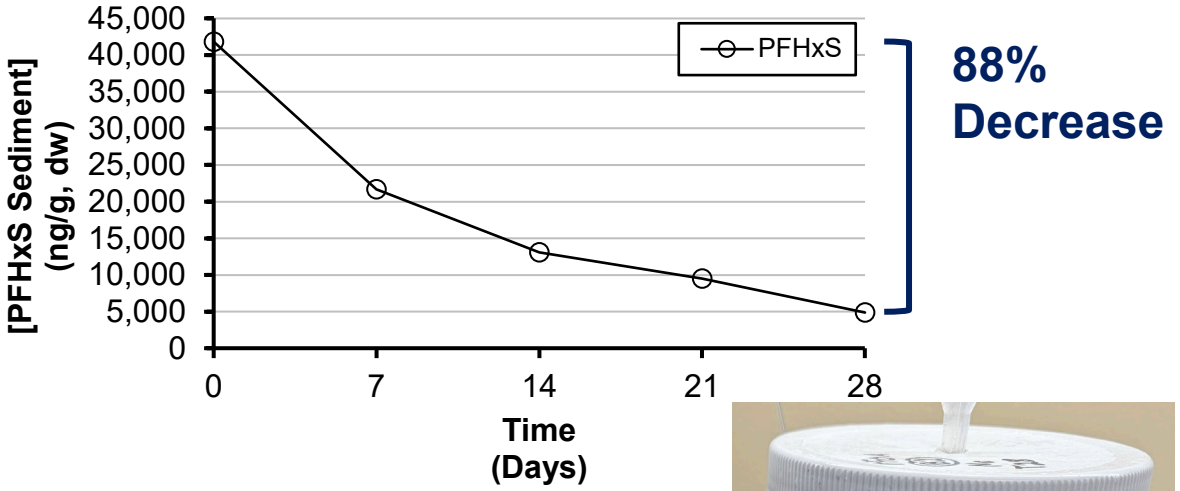
BCF = Concentration Shrimp / Concentration Water

Draft Results
(Accepted pending minor revisions)

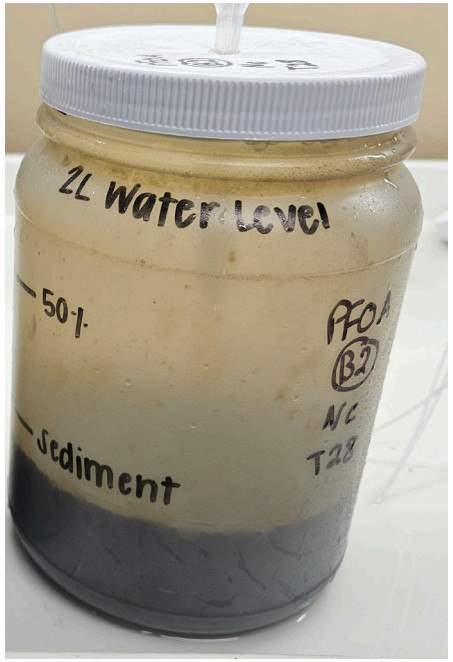
Note: The data and research presented on this slide are external grant funded research by Geosyntec and their collaborators

Longer Chained PFAS Stick to Sediment





- Shorter-chained PFAS (e.g., PFHxS) were lost to the overlying water and removed with water exchanges
- Longer-chained PFAS (e.g., PFOS) stayed in the sediment



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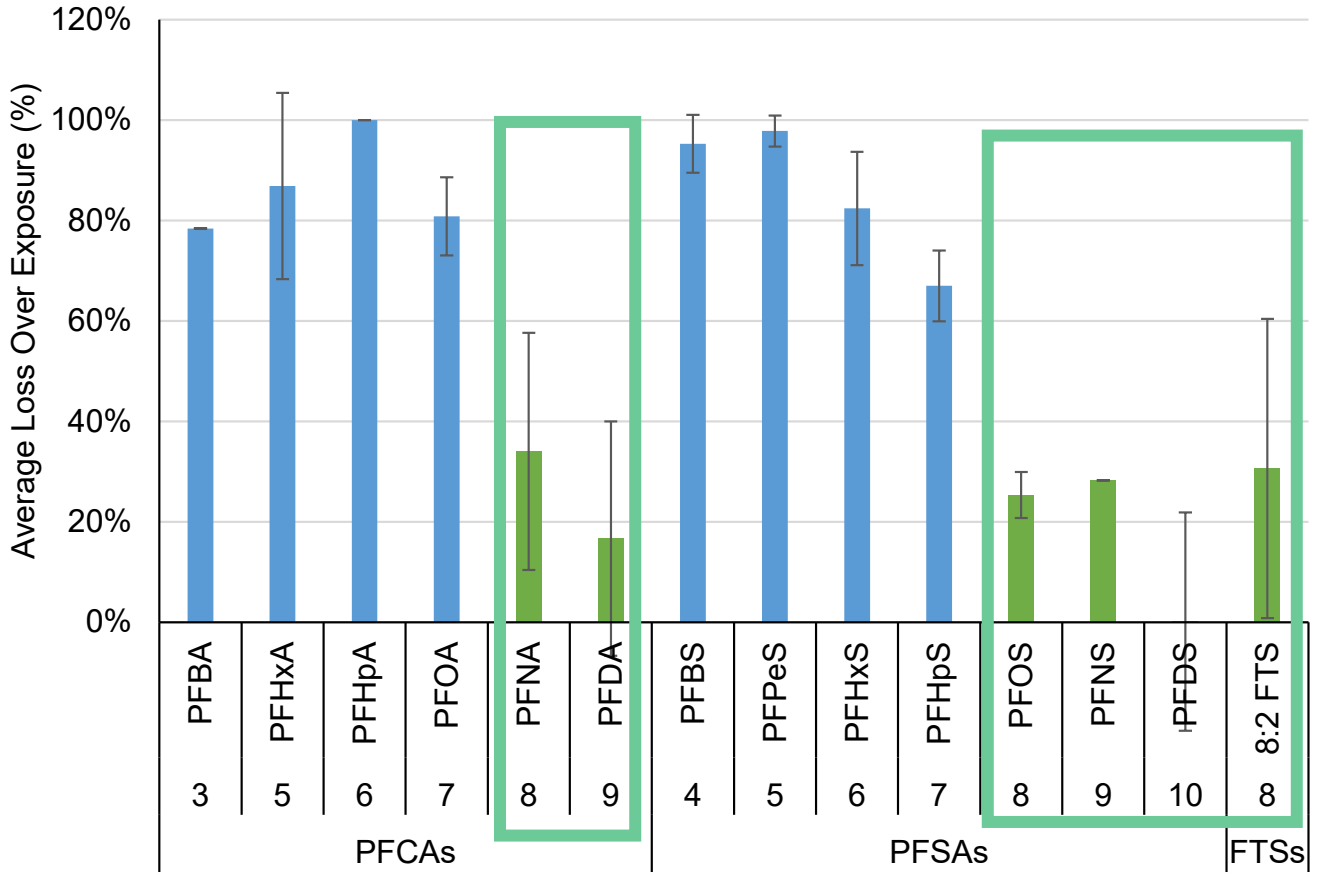
Longer Chained PFAS Stick to Sediment



KEY POINT

PFAS ≥8 perfluorinated carbons partitioned to sediment

Draft Results (in peer review)

Note: The data and research presented on this slide are external grant funded research by Geosyntec and their collaborators

PFAS In Sediment Summary

KEY POINT

PFAS can bind to and remain in aquatic sediment

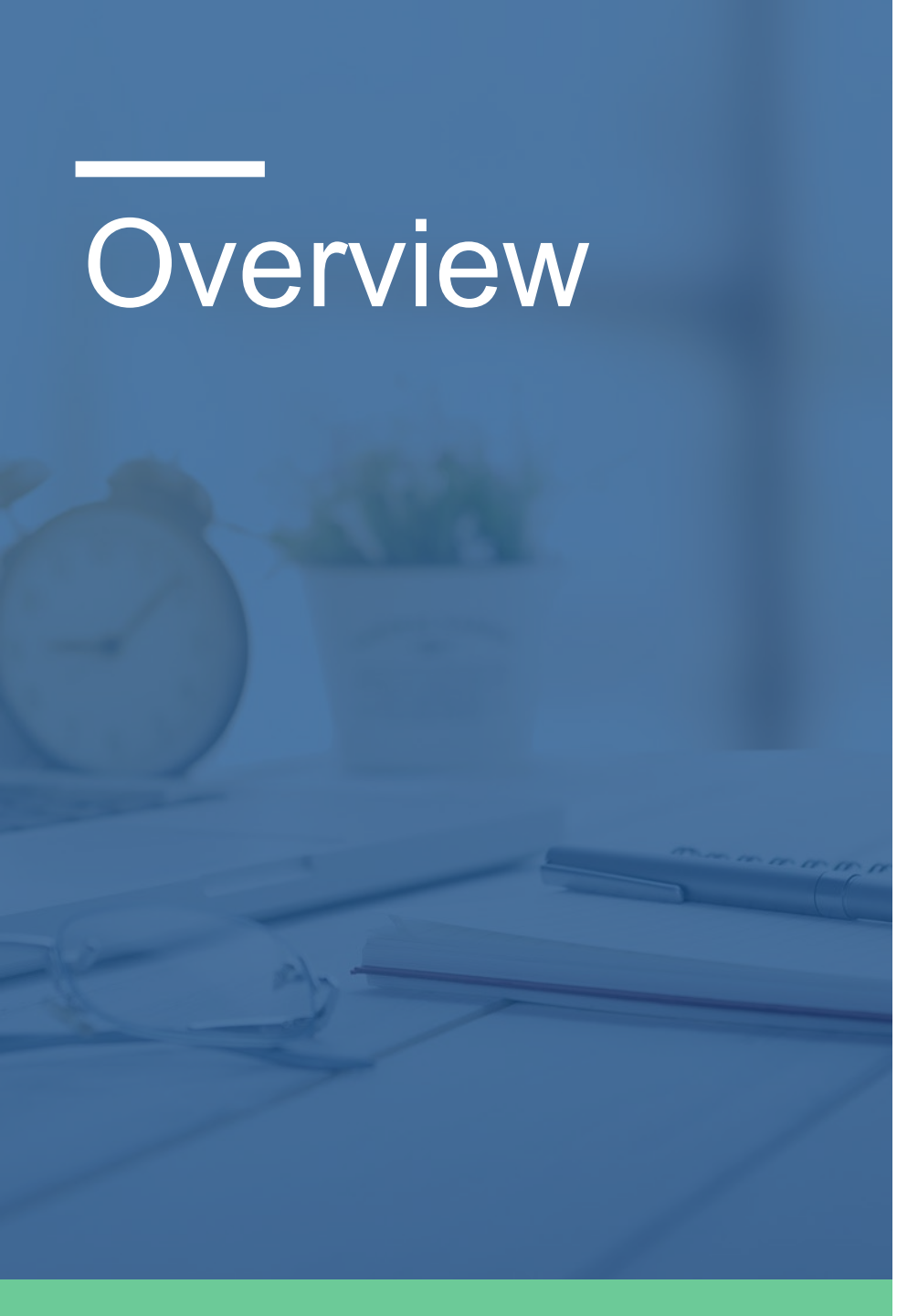
KEY POINT

Longer chained PFAS bind with sediment

KEY POINT

Toxicity and bioaccumulation is higher with longer chain length

Overview



Overview of PFAS in Sediment

- Characteristics, Toxicity, Nature and Extent

Occurrence in Pacific Northwest

Site-Specific Risk Assessment

Ecotoxicity and Bioaccumulation

Summary/Closing Statements

PFAS Occurrence in the Pacific Northwest

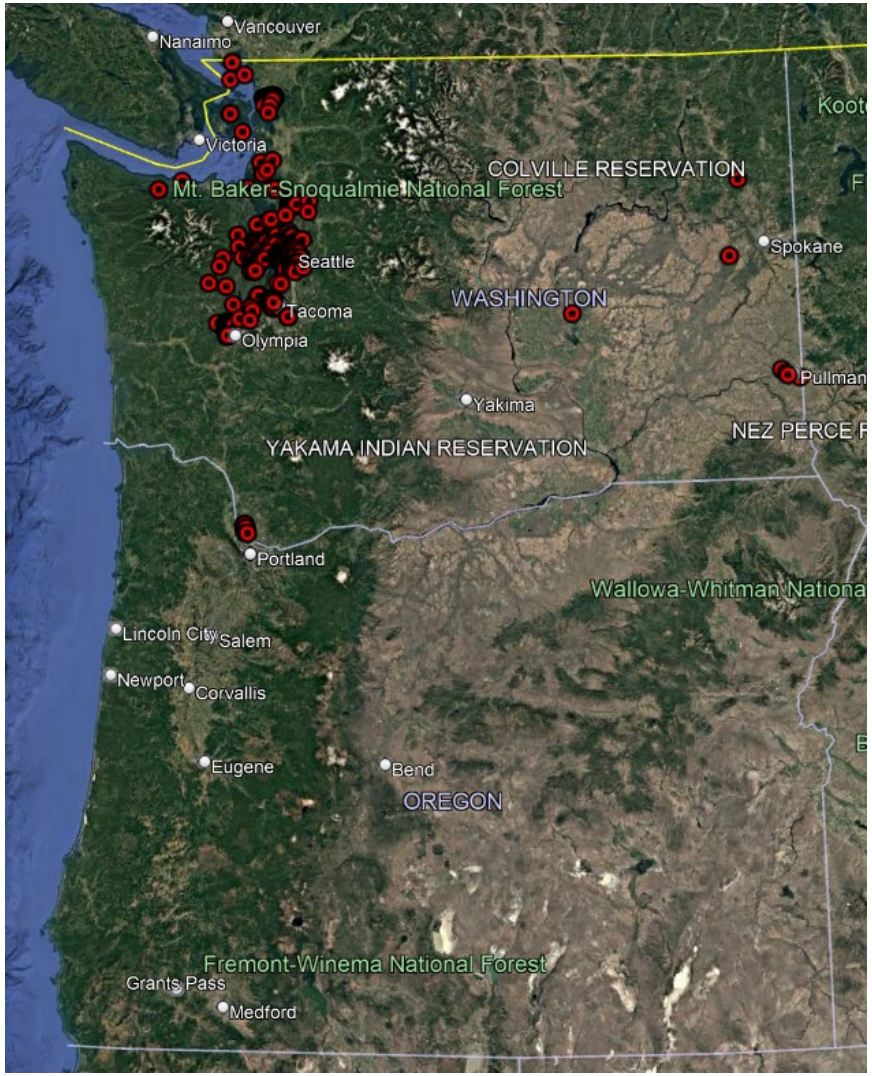
A state-of-the-science review by Geosyntec (for ECOLOGY) evaluated available data:

- Identify and compile available PFAS biota and sediment data from the Pacific Northwest
- Synthesize available PFAS toxicity data relevant to Sediment
- Develop Data Spreadsheets and visual summaries

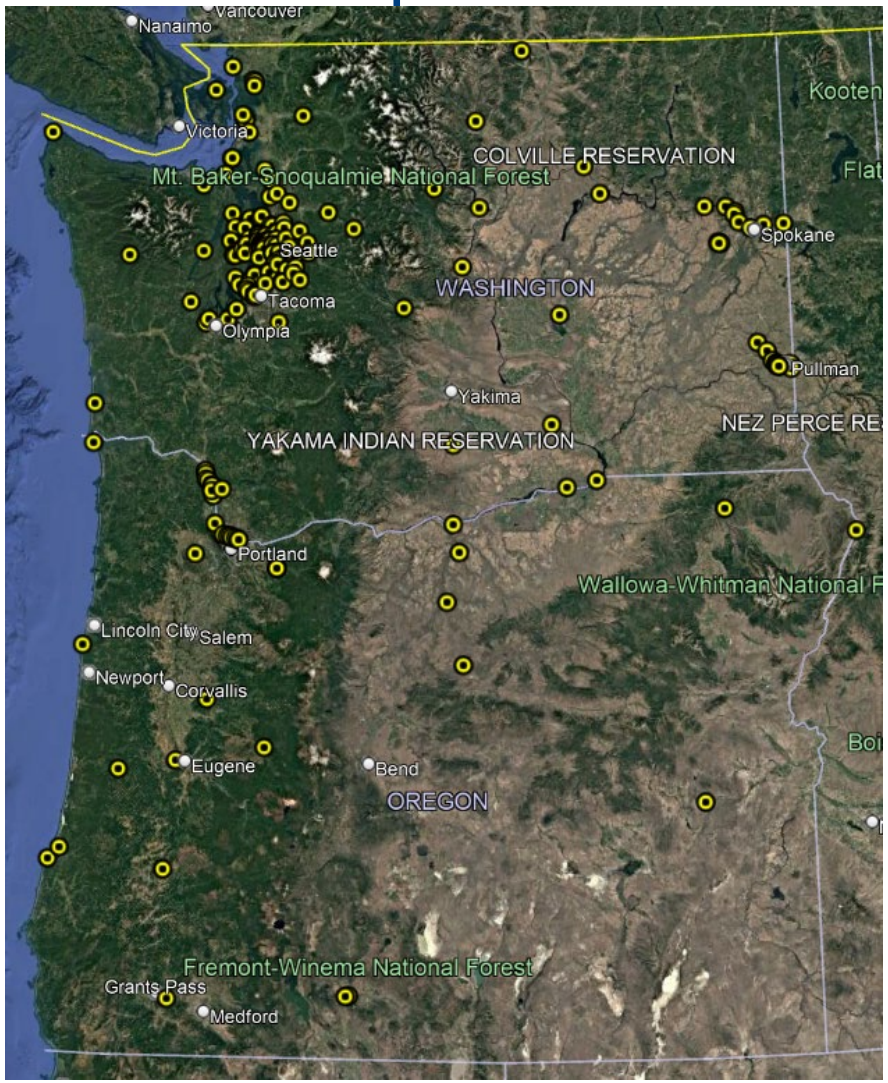
Supporting ECOLOGY'S future work

PFAS in the Pacific Northwest

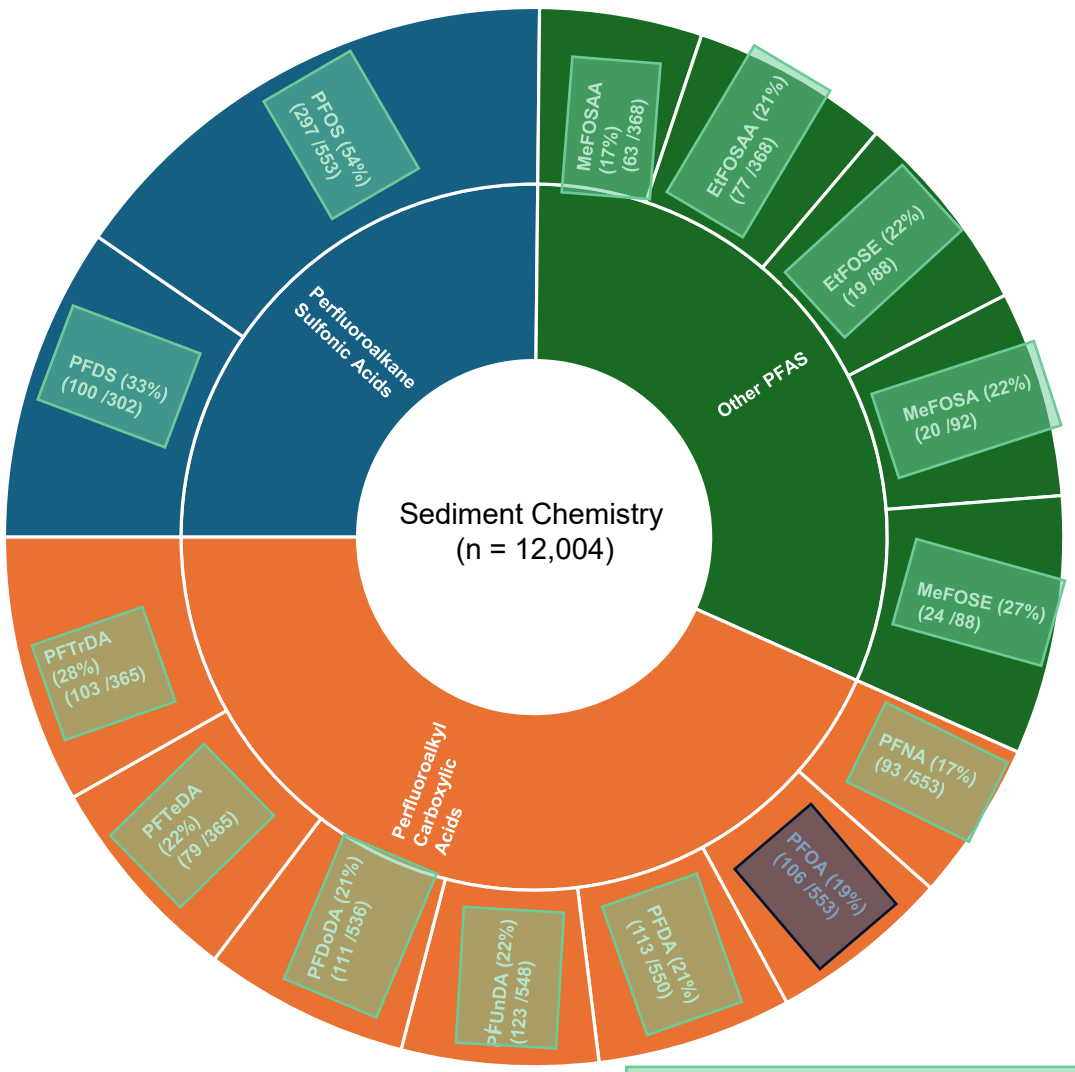
Sediment Sample Locations

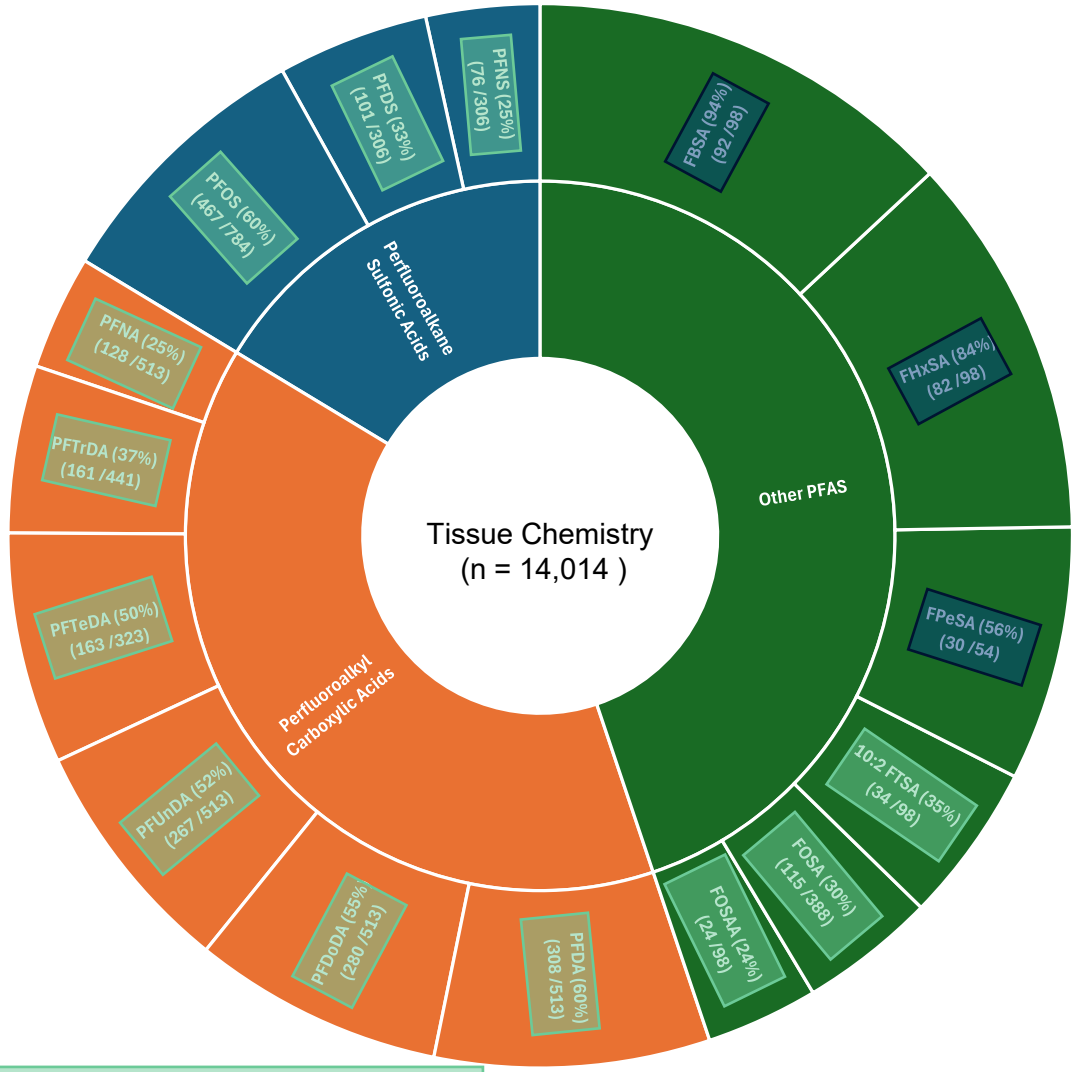


Tissue Sample Locations



PFAS With ≥ 8 Perfluorinated Carbons Are The Most Frequently Detected PFAS in Sediment and Animals

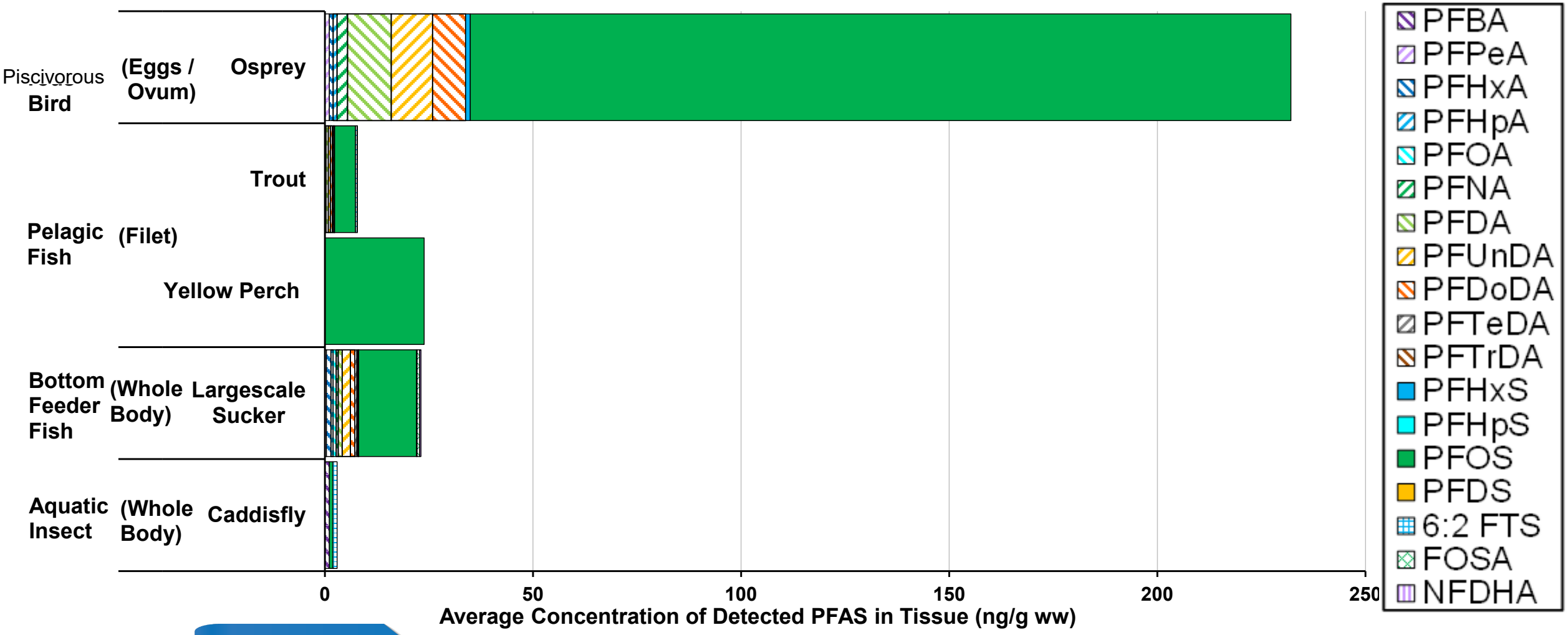




Sediment Associated PFAS ≥ 8 perfluorinated C

Water Associated PFAS < 8 perfluorinated C

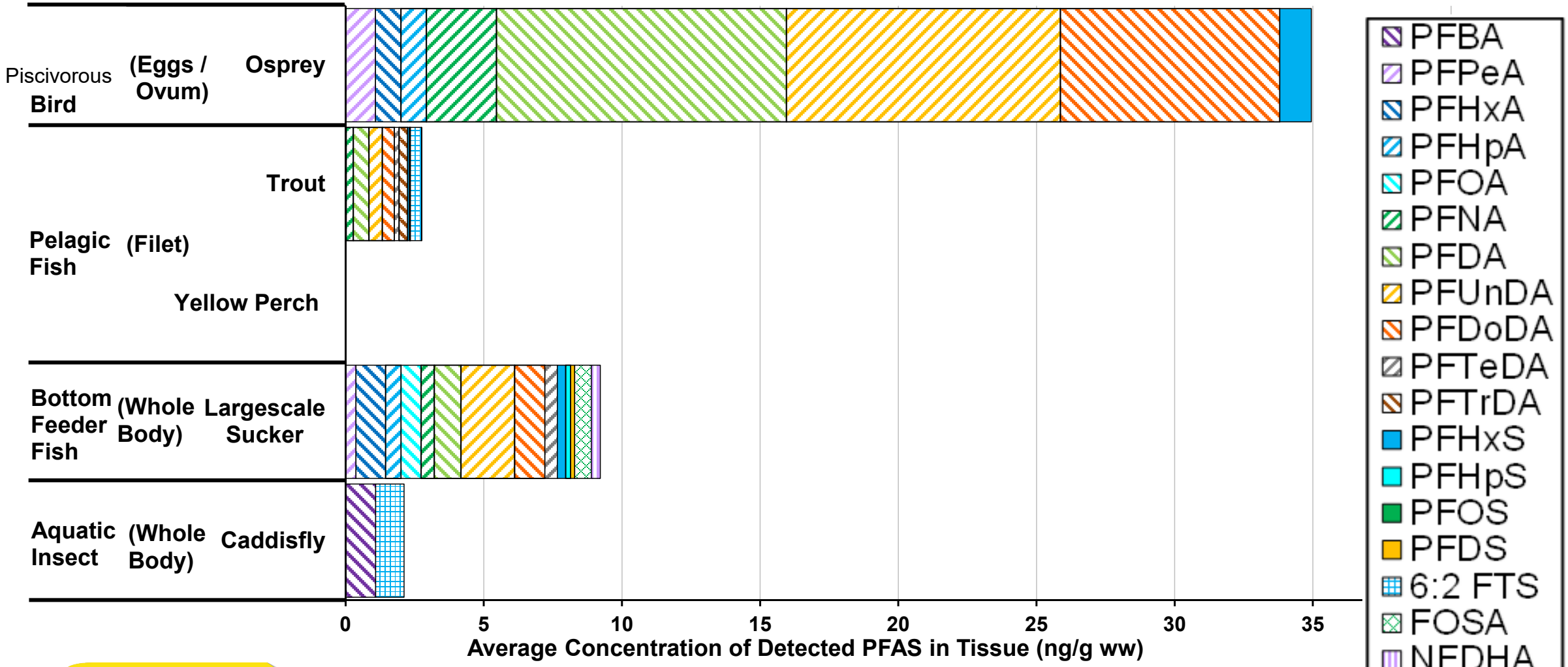
Average Detected PFAS in Freshwater Aquatic and Aquatic Dependent Wildlife Tissue



KEY POINT

PFOS is detected most frequently and at the highest concentrations

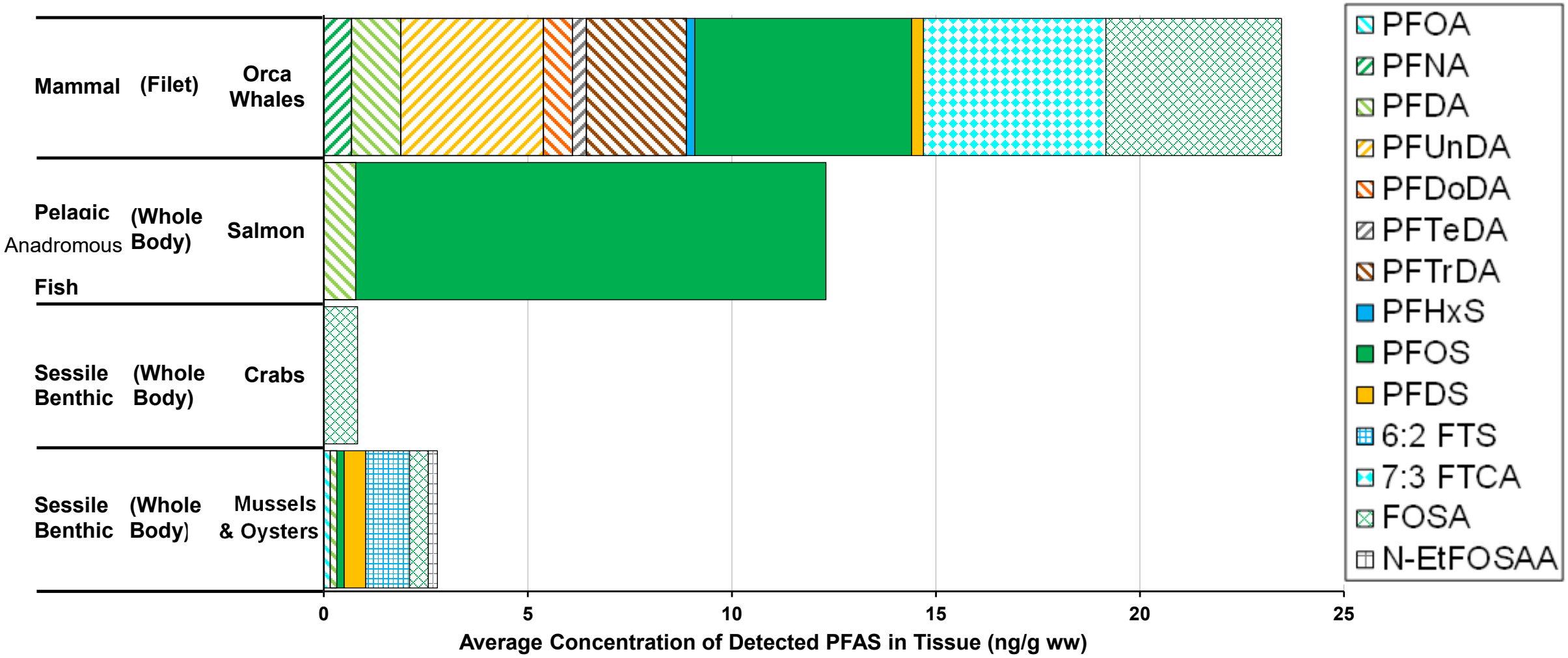
Average Detected PFAS in Freshwater Aquatic and Aquatic Dependent Wildlife Tissue Excluding PFOS



KEY POINT

PFAS ≥ 8 perfluorinated carbons are more commonly detected in animal tissue

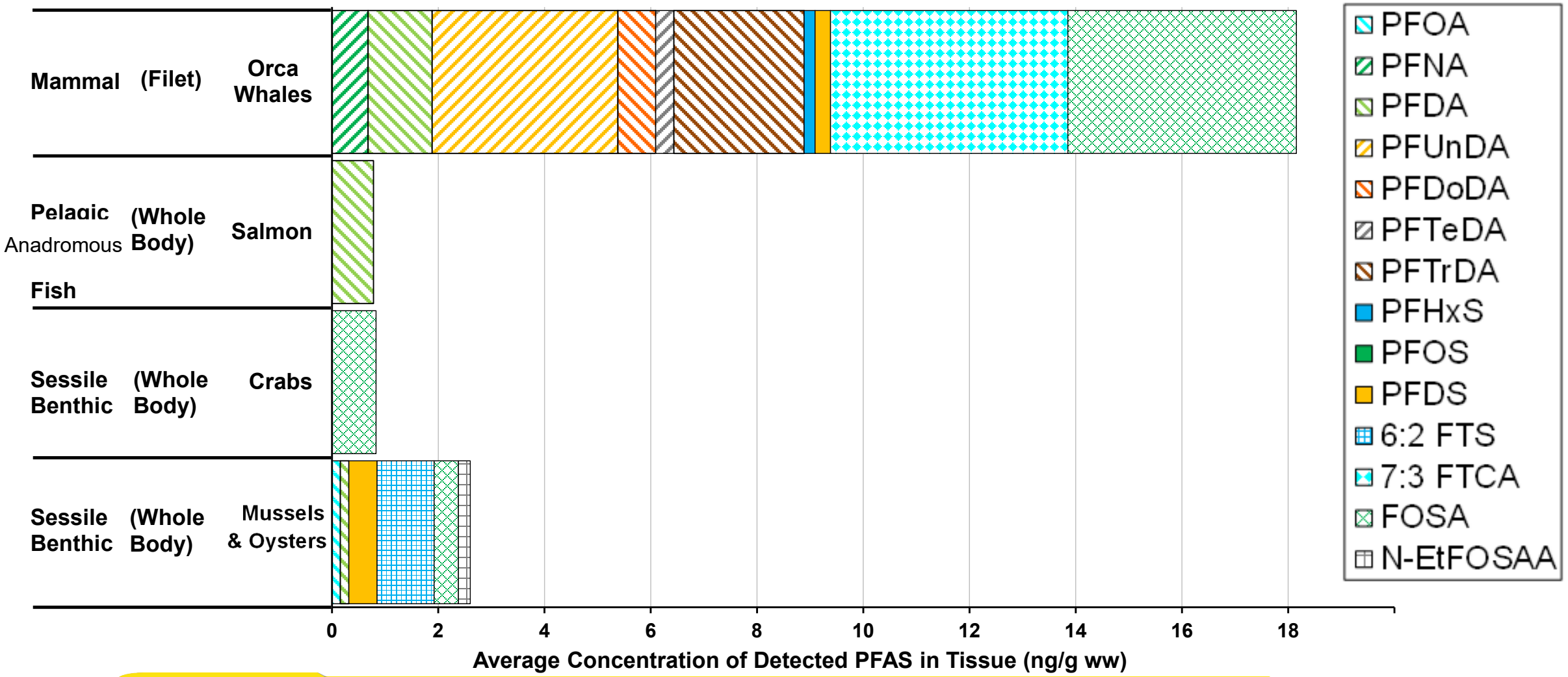
Average Detected PFAS in Marine Aquatic and Aquatic Dependent Wildlife Tissue



KEY POINT

PFOS is detected at high concentrations in marine animals relative to other PFAS

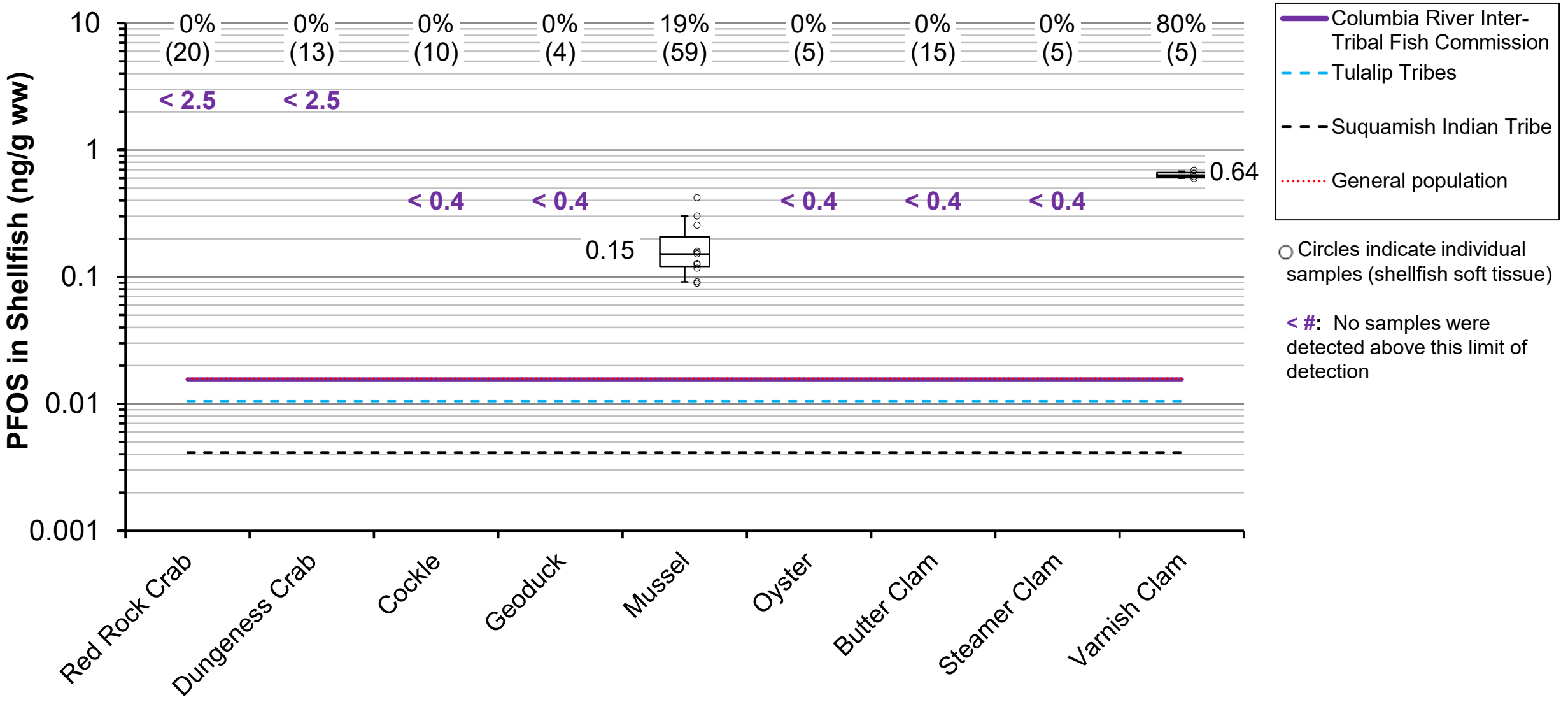
Average Detected PFAS in Marine Aquatic and Aquatic Dependent Wildlife Tissue Excluding PFOS



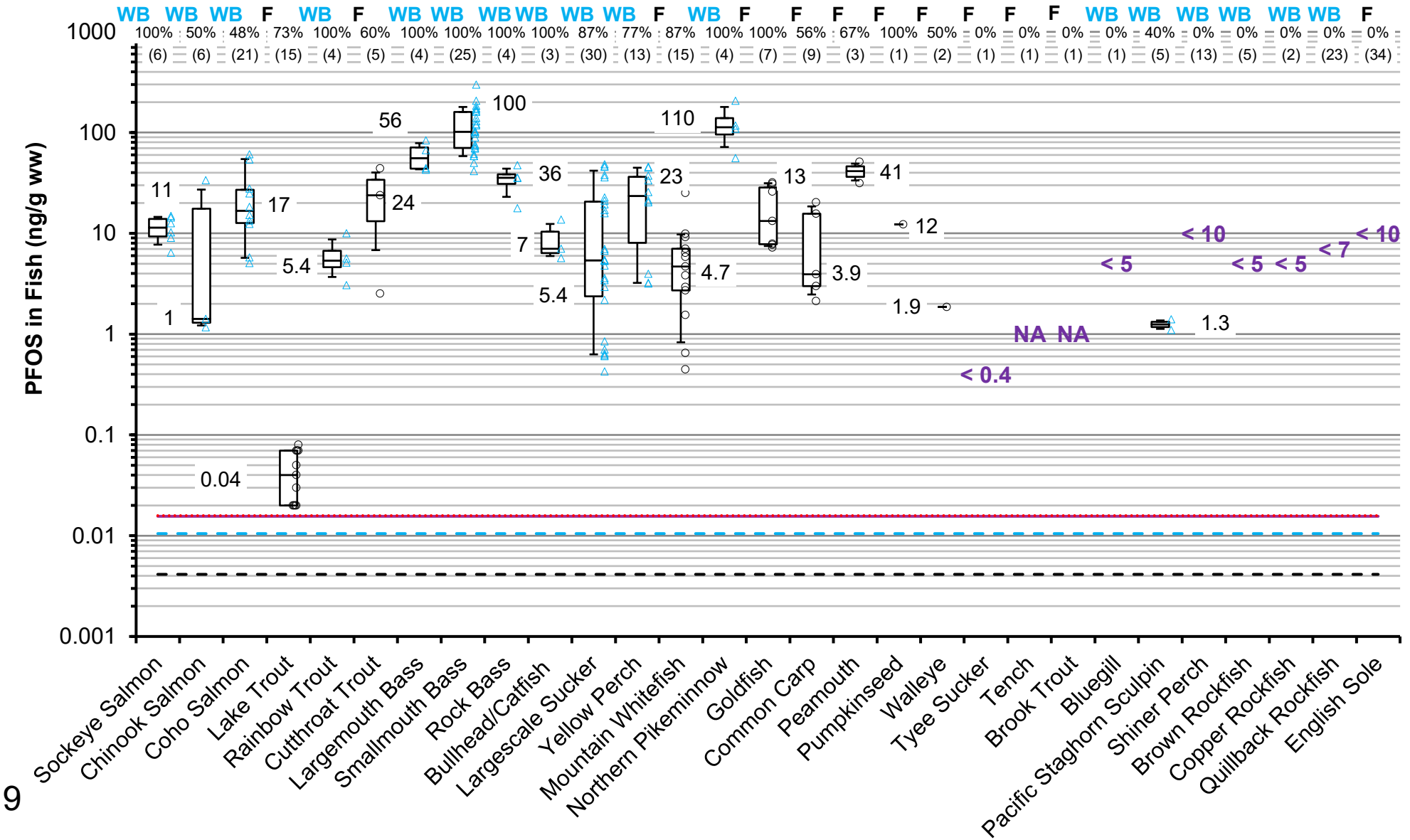
KEY POINT

PFAS ≥ 8 perfluorinated carbons are more commonly detected in animal tissue

Shellfish Tissue Concentrations Exceed Calculated Risk-Based Tissue Concentrations



Fish Tissue Concentrations Exceed Calculated Risk-Based Tissue Concentrations



Columbia River Inter-Tribal Fish Commission

Tulalip Tribes

Suquamish Indian Tribe

General population

Whole Body (**WB**)

Fillet (**F**)

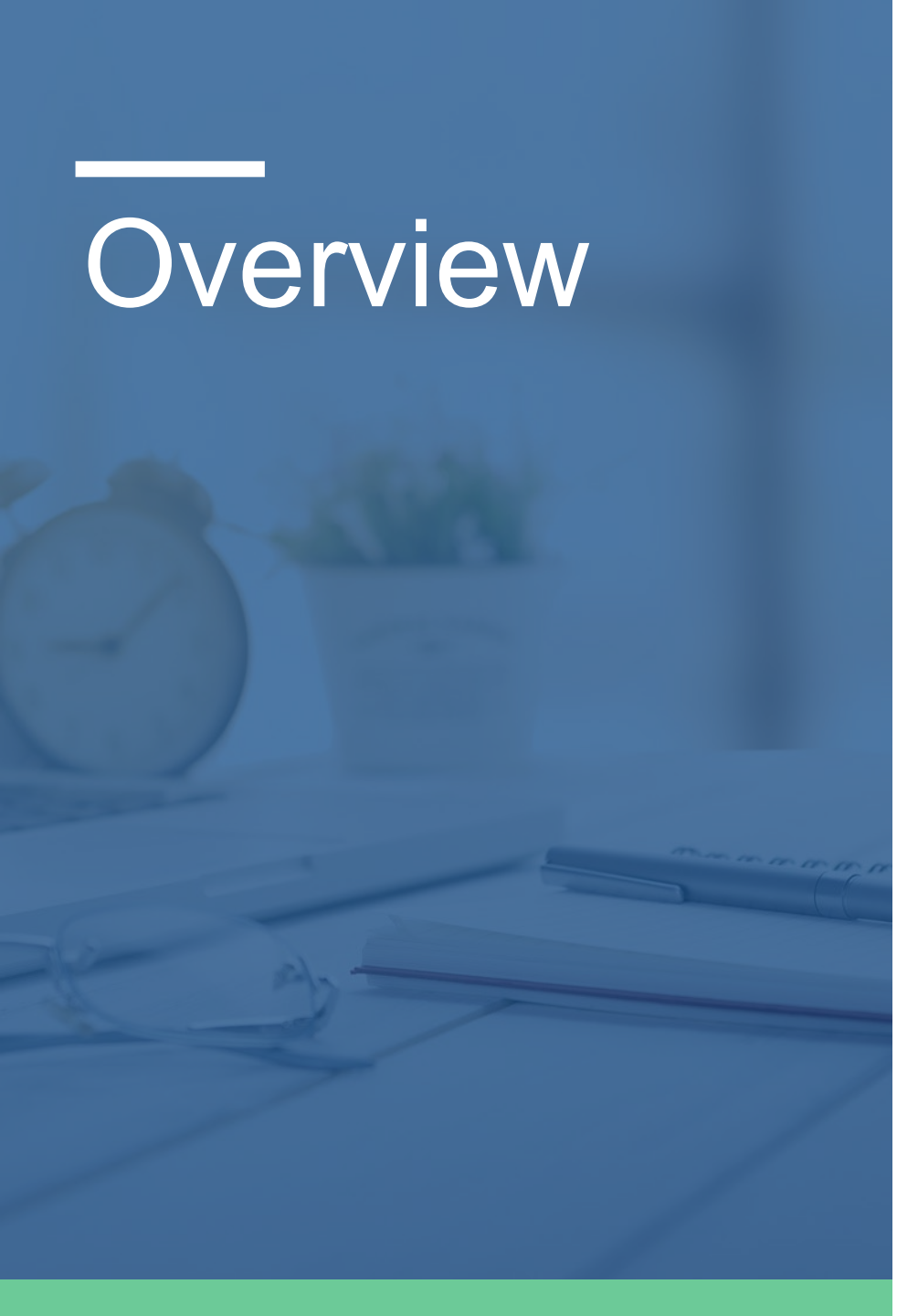
< #: No samples were detected above this limit of detection

NA: All samples were non-detect and no limit of detection available

PFAS in the Pacific Northwest Conclusions

- PFAS are found in freshwater/marine sediments
- As PFAS in sediment can enter the water table it is possible that a proportion of PFAS in aquatic life is from sediment
- PFOS is the PFAS with the highest detected concentration in animal tissue
- PFAS found in freshwater and marine sediment tend to be ≥ 8 perfluorinated carbons long

Overview



Overview of PFAS in Sediment

- Characteristics, Toxicity, Nature and Extent

Occurrence in Pacific Northwest

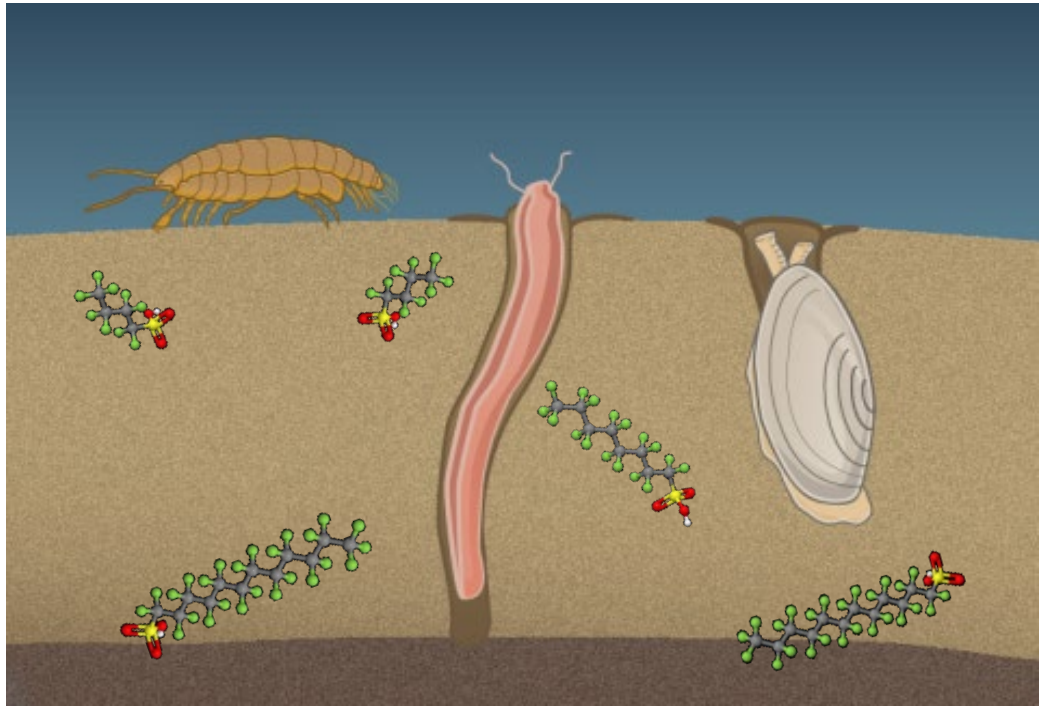
Site-Specific Risk Assessment

Ecotoxicity and Bioaccumulation

Summary/Closing Statements

Risk Considerations

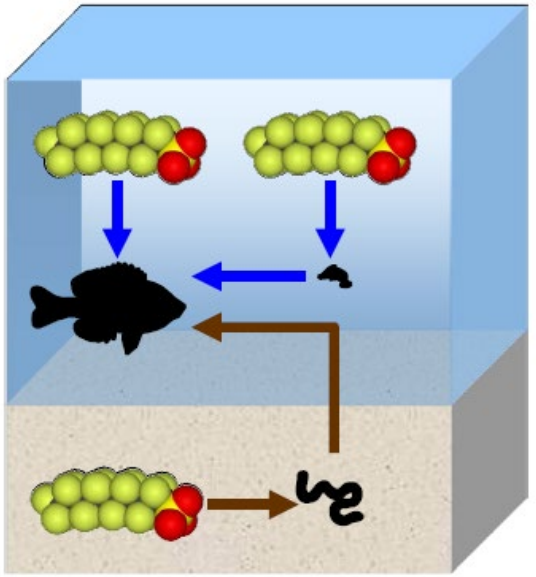
- Risk assessment is possible for some PFAS
  - Toxicological benchmarks (aquatic life values, human health reference doses, human health cancer slope factors, wildlife toxicity reference values) are available
  - Some sediment screening levels are available



Managing PFAS Risk: Sediment vs. Water

PFOS is found in both sediment and water

Modeling at case study sites (Larson et al., 2018) indicates majority of PFOS in food webs originates in sediment compared to water



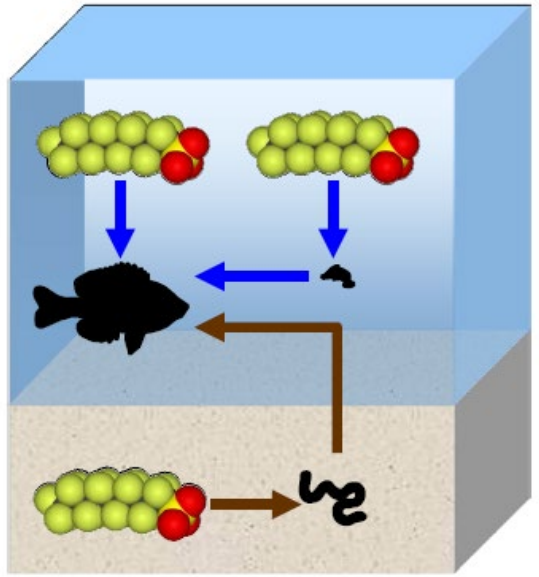
Larson, E.S., Conder, J.M., Arblaster, J.A. (2018) Modelling avian exposures to perfluoroalkyl substances in aquatic habitats impacted by historical aqueous film forming foam releases. Chemosphere 201:335-341.

Managing PFAS Risk: Sediment vs. Water

PFOS is found in both sediment and water

Modeling at case study sites (Larson et al., 2018) indicates majority of PFOS in food webs originates in sediment compared to water

- Yes, “it’s only a model”

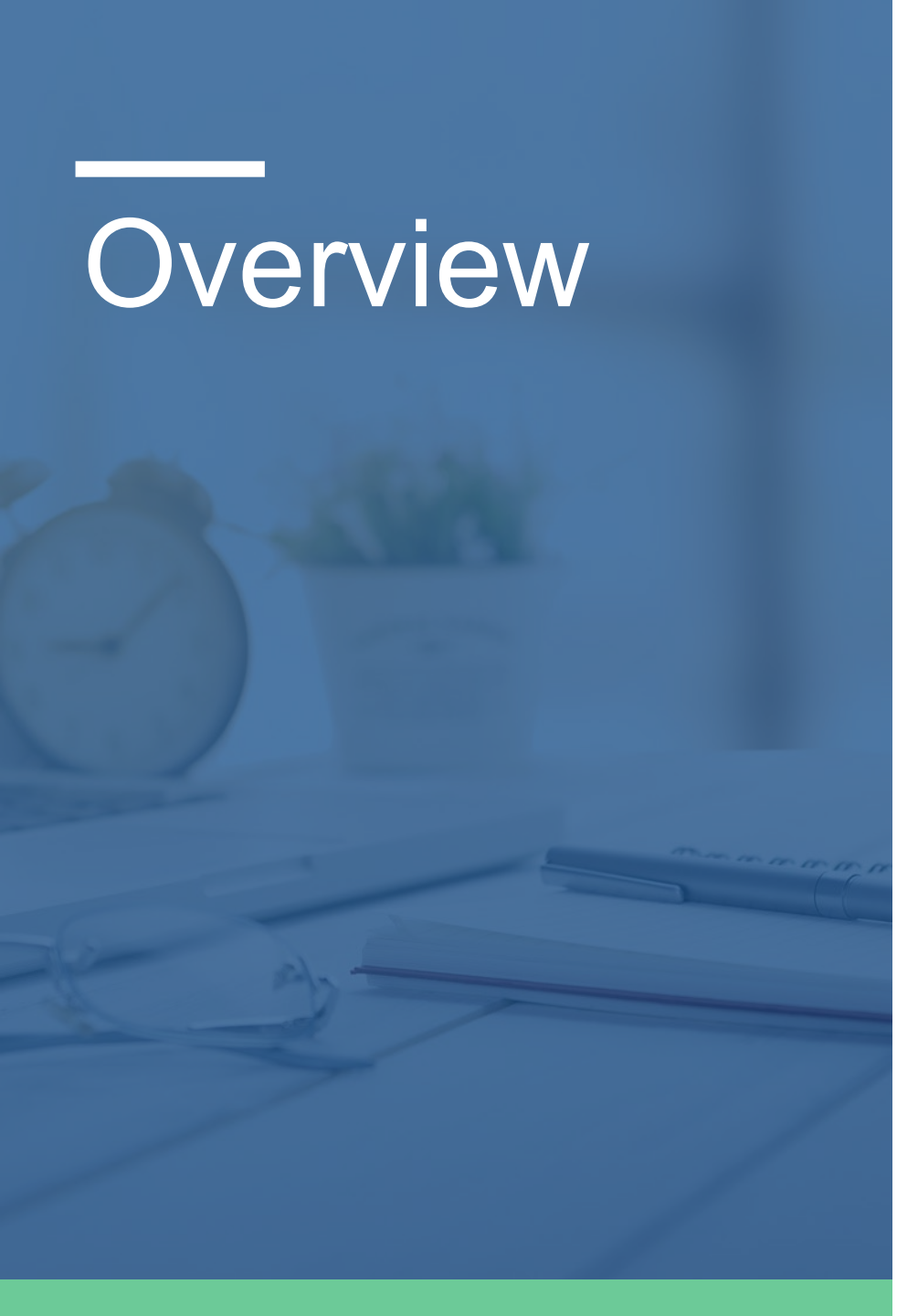


- At many sites, concentrations of PFOS in benthic invertebrates are similar to or higher than fish

KEY POINT

Addressing PFAS in sediment will likely include site-specific decisions

Overview



Overview of PFAS in Sediment

- Characteristics, Toxicity, Nature and Extent

Occurrence in Pacific Northwest

Site-Specific Risk Assessment

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Summary/Closing Statements

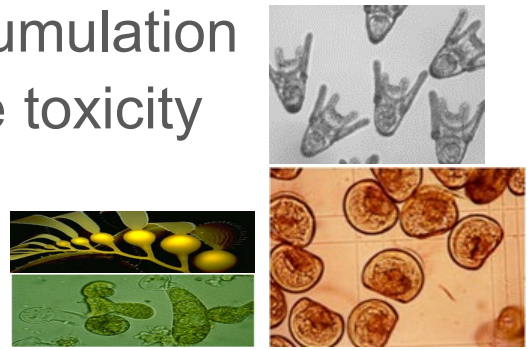
PFAS Marine Toxicity Research

Objectives

- Fill data gaps by generating marine toxicological data
- Derive chronic toxicity, uptake factors, mixture toxicity
- Improve ecological risk assessment of PFAS-impacted sites

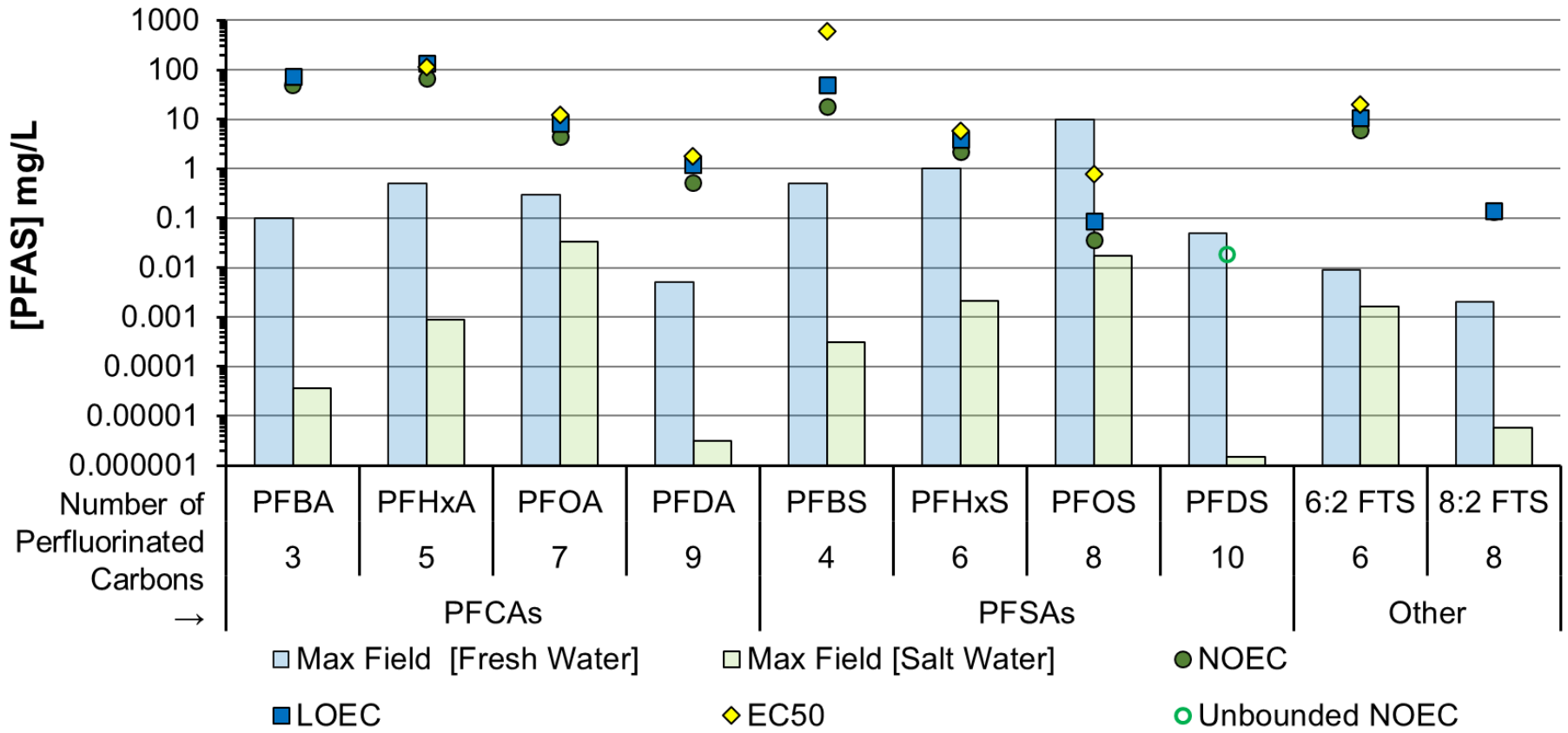
Studies

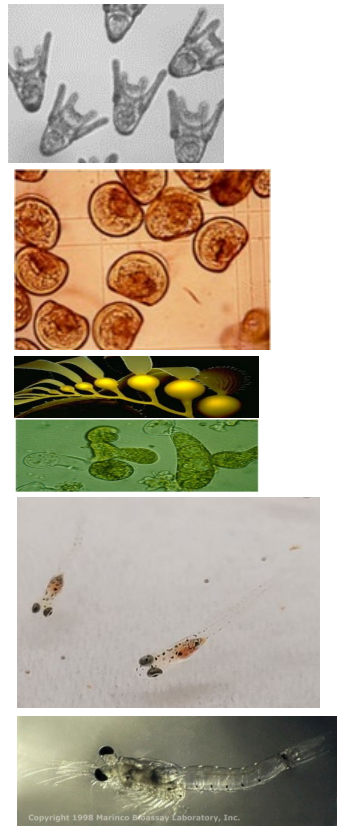
- Evaluation of 10 PFAS for 5 pelagic species – toxicity and bioaccumulation
- Evaluation of 6 sediment-associated PFAS for 2 benthic species – toxicity and bioaccumulation
- Mixture toxicity



Note: The data and research presented on this slide are external grant funded research by Geosyntec and their collaborators

Single-PFAS Marine Water Effect Benchmarks





Max = maximum, LOEC = lowest observed effect concentration, NOEC = no observed effect concentration, EC50 = effective concentration to cause a 50% reduction in growth, Unbounded NOEC = all concentrations tested were no effect, the highest tested concentration is displayed

KEY POINT

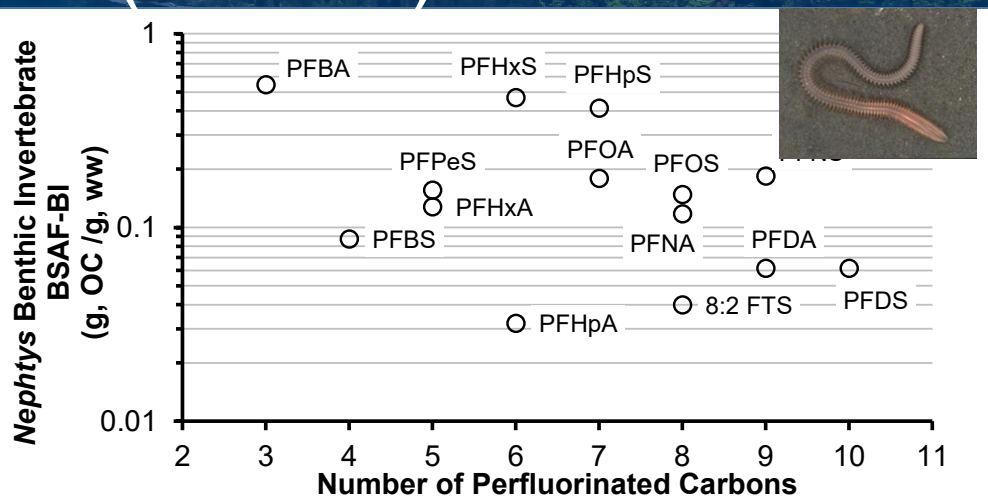
Adverse effects in the 5 pelagic species tested occur at surface water concentrations orders of magnitude higher than occur at Sites

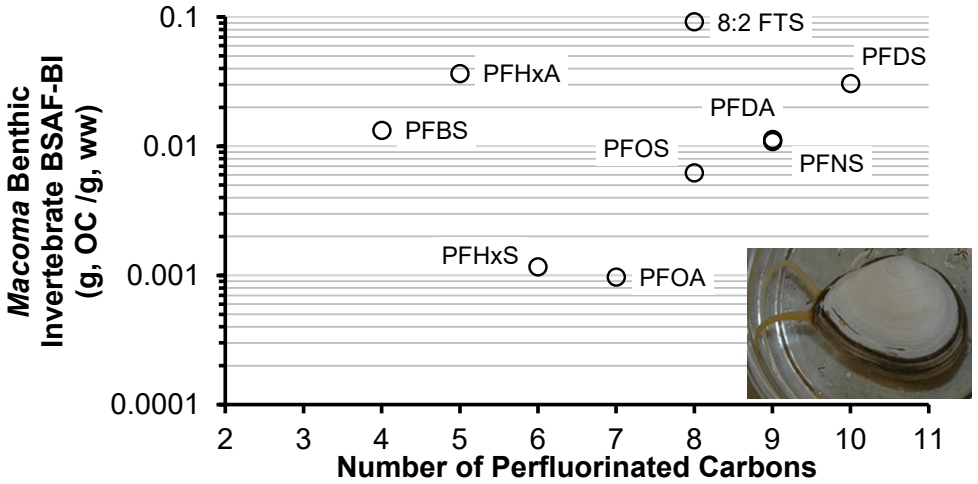
Note: The data and research presented on this slide are external grant funded research by Geosyntec and their collaborators

Sediment Bioaccumulation Results – Biota-Sediment Accumulation Factors (BSAFs)

Nephtys BSAFs are

- 1 order of magnitude **higher** than *Macoma*
- 1 order of magnitude **lower** than freshwater oligochaete (Higgins et al. 2007)





Note: Normalized to organic carbon in sediment

KEY POINT

Poor relationship between perfluorinated carbon chain length and uptake relative to bulk sediment concentrations

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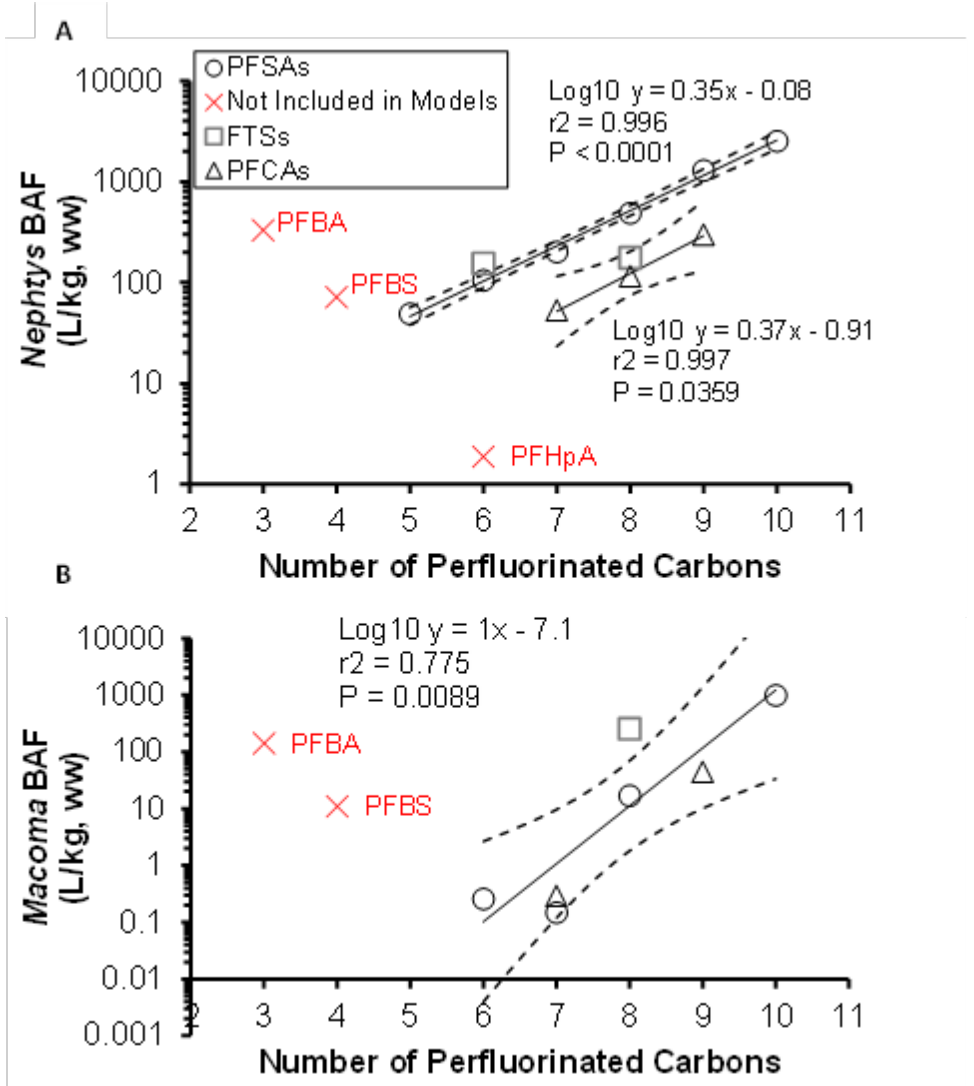
Sediment Bioaccumulation Results – Porewater Derived Bioaccumulation Factors (BAFs)

- Expected relationship between perfluorinated chain length and BAF observed, especially by functional group



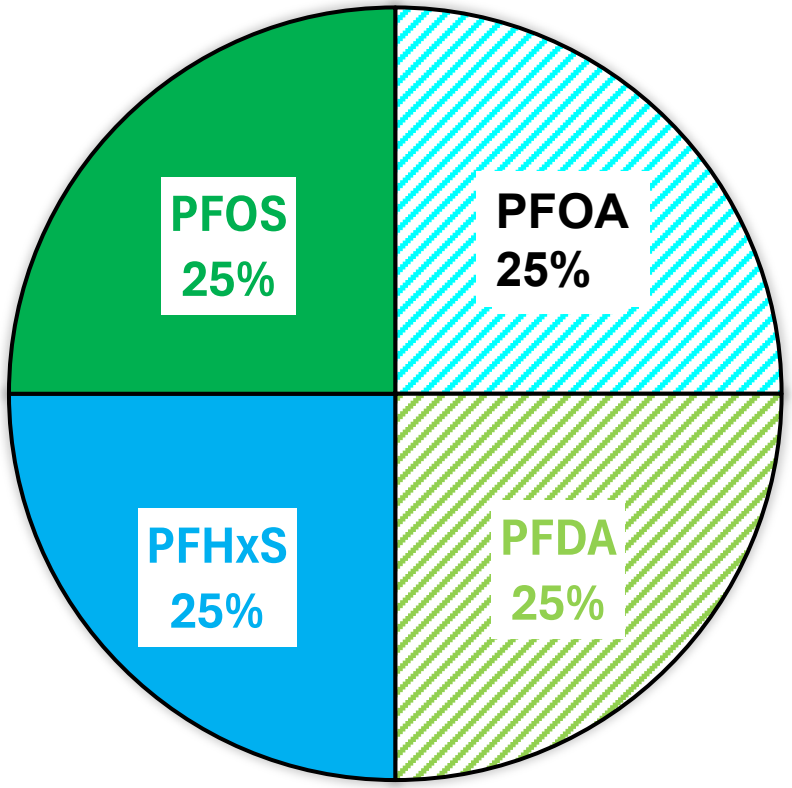
KEY POINT

Porewater concentrations are a better indicator of bioavailability than bulk sediment

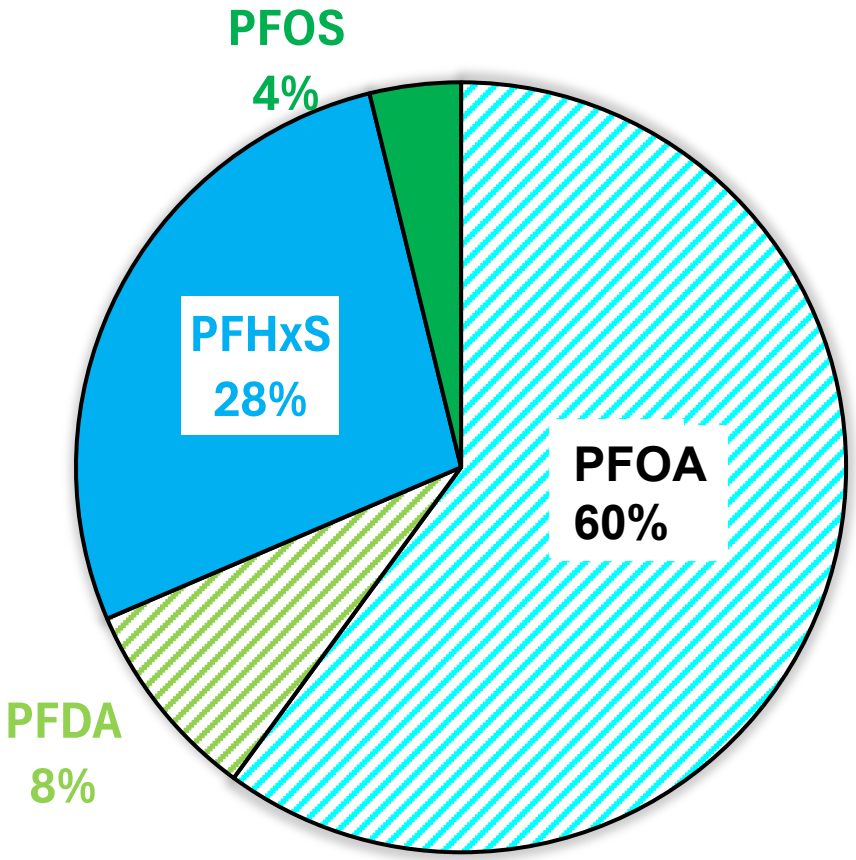
Note: The data and research presented on this slide are external grant funded research by Geosyntec and their collaborators

Mixture Testing: Equitoxic Mixture

BY TOXIC UNITS



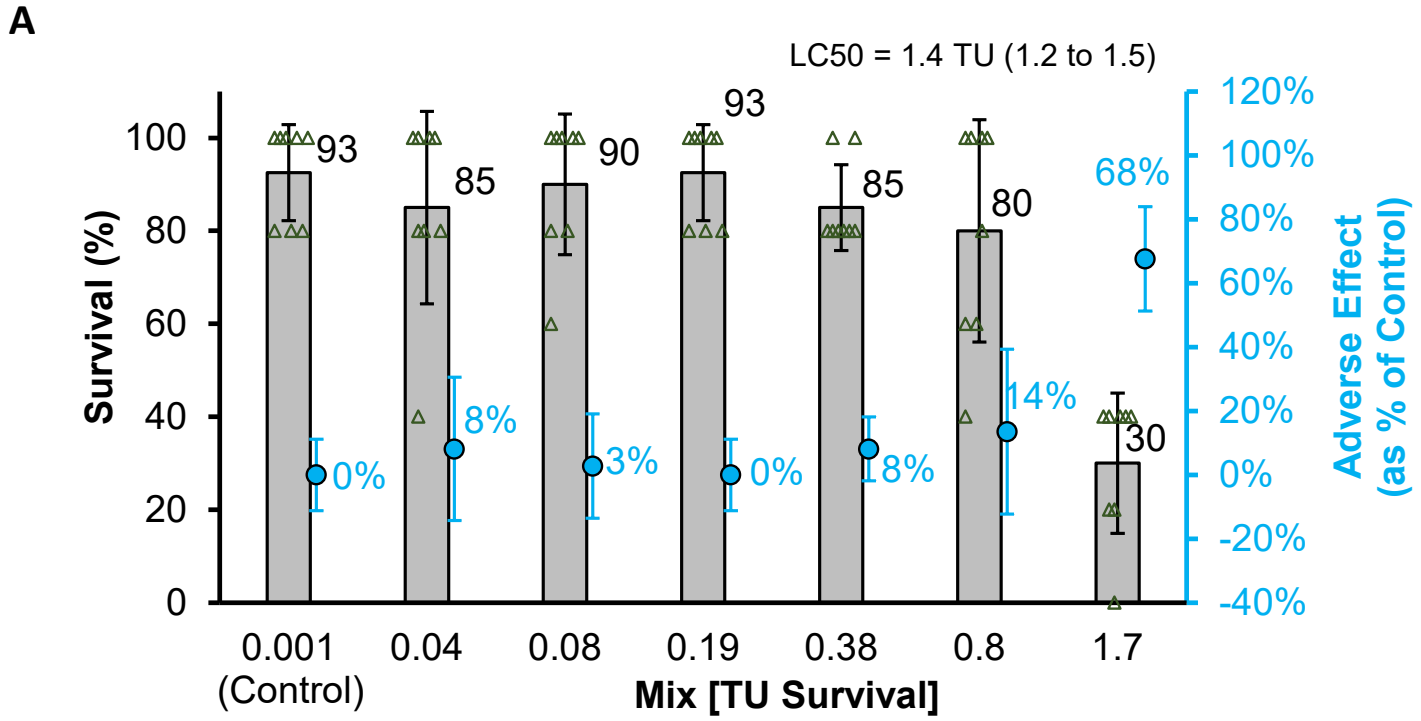
BY CONCENTRATION



e.g. The concentration to cause a 50% reduction in growth of PFOS was 1 mg/L and PFOA was 100 mg/L
A binary mixture using equitoxic TUs would be 0.5 mg/L PFOS and 50 mg/L PFOA and be predicted to cause a 50% effect (if additive)

Note: The data and research presented on this slide are external grant funded research by Geosyntec and their collaborators

Mixture Testing: Equitoxic Mixture



Test 121 Equitoxic mixtures (PFOA, PFDA, PFHxS, and PFOS)
Mysid Shrimp Preliminary Mixture Results [Measured TU]

KEY POINT

Mixtures of PFAS cause toxicity in an additive manner

- **We can predict the risk of mixtures of PFAS using this method**
- **We could evaluate risk of PFAS like how we do for PAH mixtures**

Note: The data and research presented on this slide are external grant funded research by Geosyntec and their collaborators

PFAS in Bivalves Study Objectives

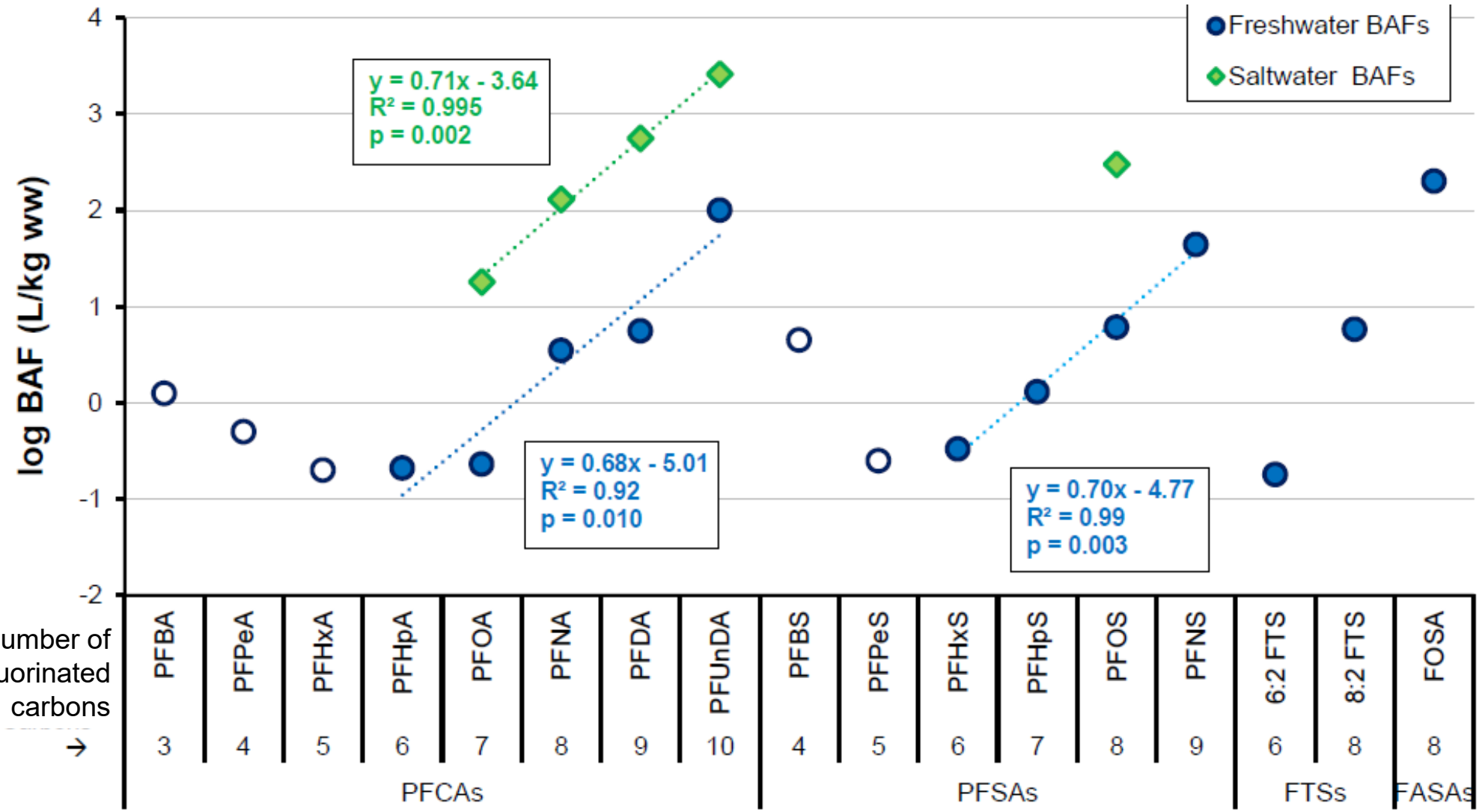
- Benthic biota, such as bivalves, may be more susceptible than other seafood to contamination from PFAS[1,2,3]
  - Bivalves may be an important exposure pathway for consumers

- Objectives:
  - Identify robust field studies at AFFF sites where PFAS was measured in bivalve tissues (and preferably at least an additional aquatic species like fish)
  - Identify robust laboratory studies from which water-to-tissue and sediment-to-tissue bioaccumulation metrics can be obtained

[1]Giffard et al. 2022, *Curr Envir Health Rpt* 9; [2]Brambilla 2024, *Environ Sci Pollut Res Int* 31(22);
[3]USEPA 2024, Contaminants to Monitor in Fish and Shellfish Advisory Programs

Note: The data and research presented on this slide are external grant funded research by Geosyntec and their collaborators

The Uptake of PFAS Correlates with Perfluorinated Carbon Chain Length

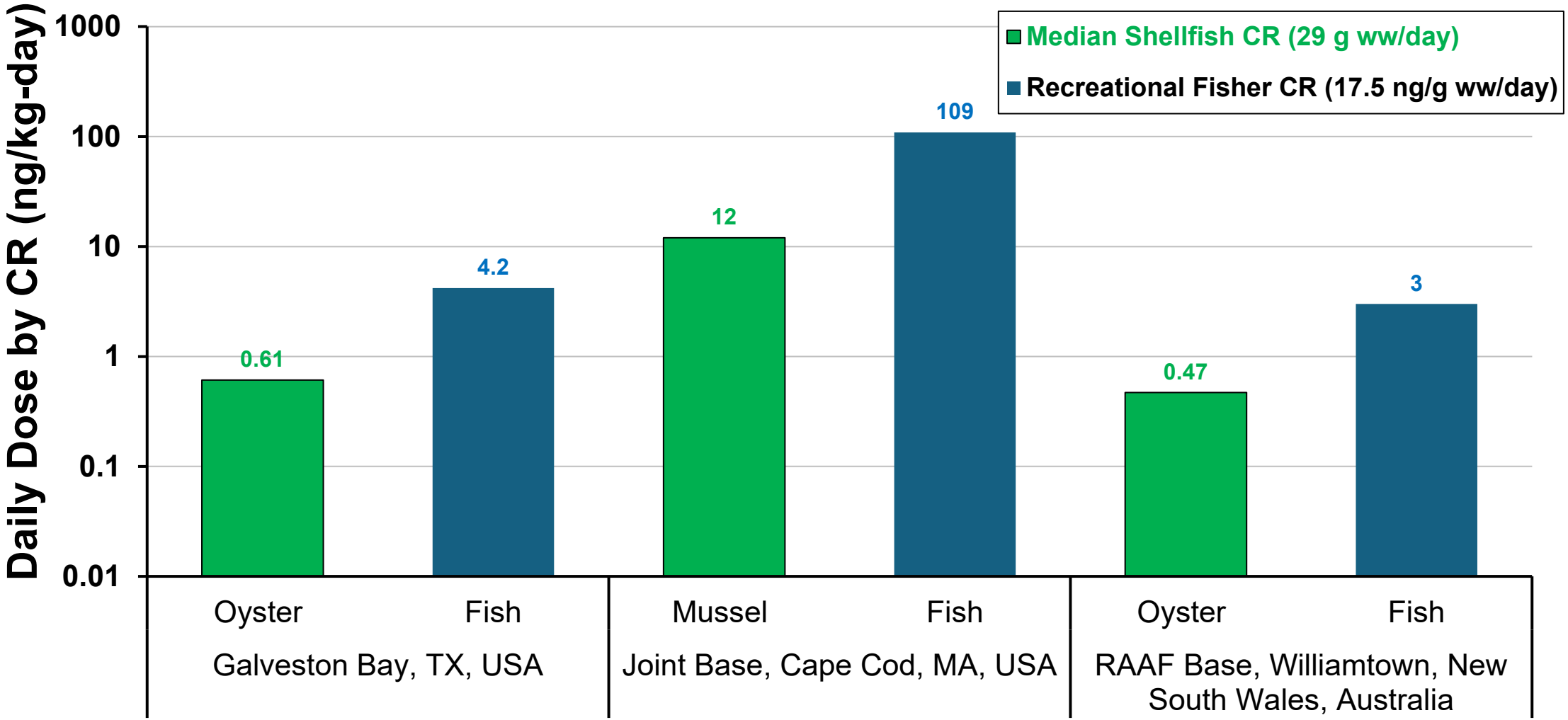


Calculated BAF

< BAF (Detected in water but not tissue)

Note: The data and research presented on this slide are external grant funded research by Geosyntec and their collaborators

The Daily Dose of PFOS is Higher for Humans Consuming Fish Relative to Shellfish From the Same Site



CR- Consumption Rate

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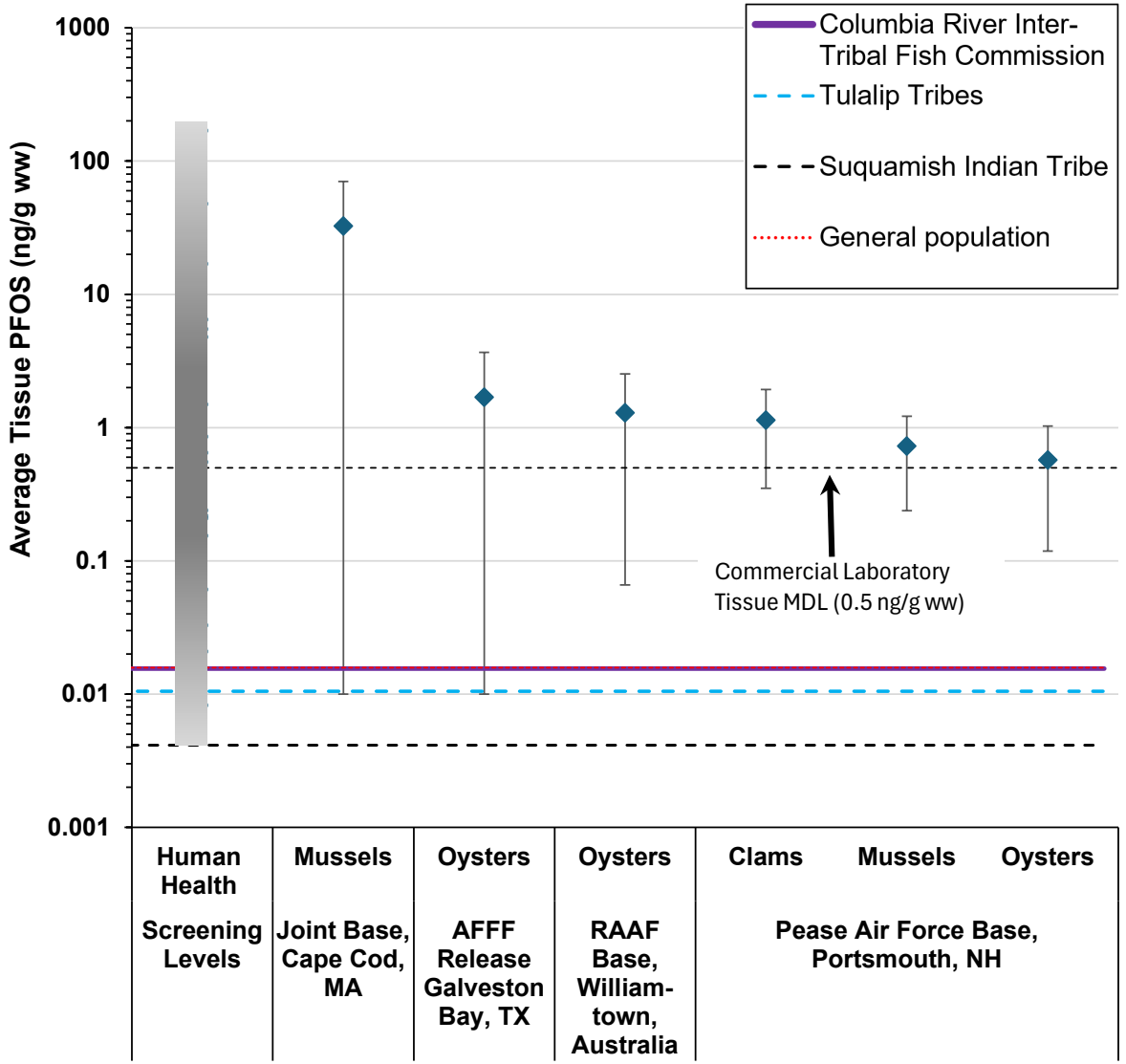
Risk of PFAS to Wildlife and Human Health



Due to the low direct toxicity of PFAS to aquatic life

- Humans consuming fish/shellfish and wildlife consuming aquatic life appear to be at highest risk, which is consistent with other bioaccumulative chemicals

Wildlife screening levels tend to be orders of magnitude higher than human health

Human health screening levels vary greatly

> 4 orders of magnitude

Note: The data and research presented on this slide are external grant funded research by Geosyntec and their collaborators

PFAS in Bivalves, Conclusions:

- Calculated uptake factors can be used to predict the accumulation of PFAS in bivalves at contaminated sites
- Bivalves can accumulate PFAS at sites to concentrations that exceed some human health screening levels
- However, compared to bivalve consumption, fish consumption at sites is more likely to drive risk-based decision making under most exposure assumptions

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Pandelides, Z. Arblaster, J. Pandelides, A.F. Nichols, E. Thapalia, A. Conder, J. 2026. Risks associated with consumption of bivalves from PFAS-impacted AFFF sites. IEAM. https://doi.org/10.1093/inteam/vjaf142

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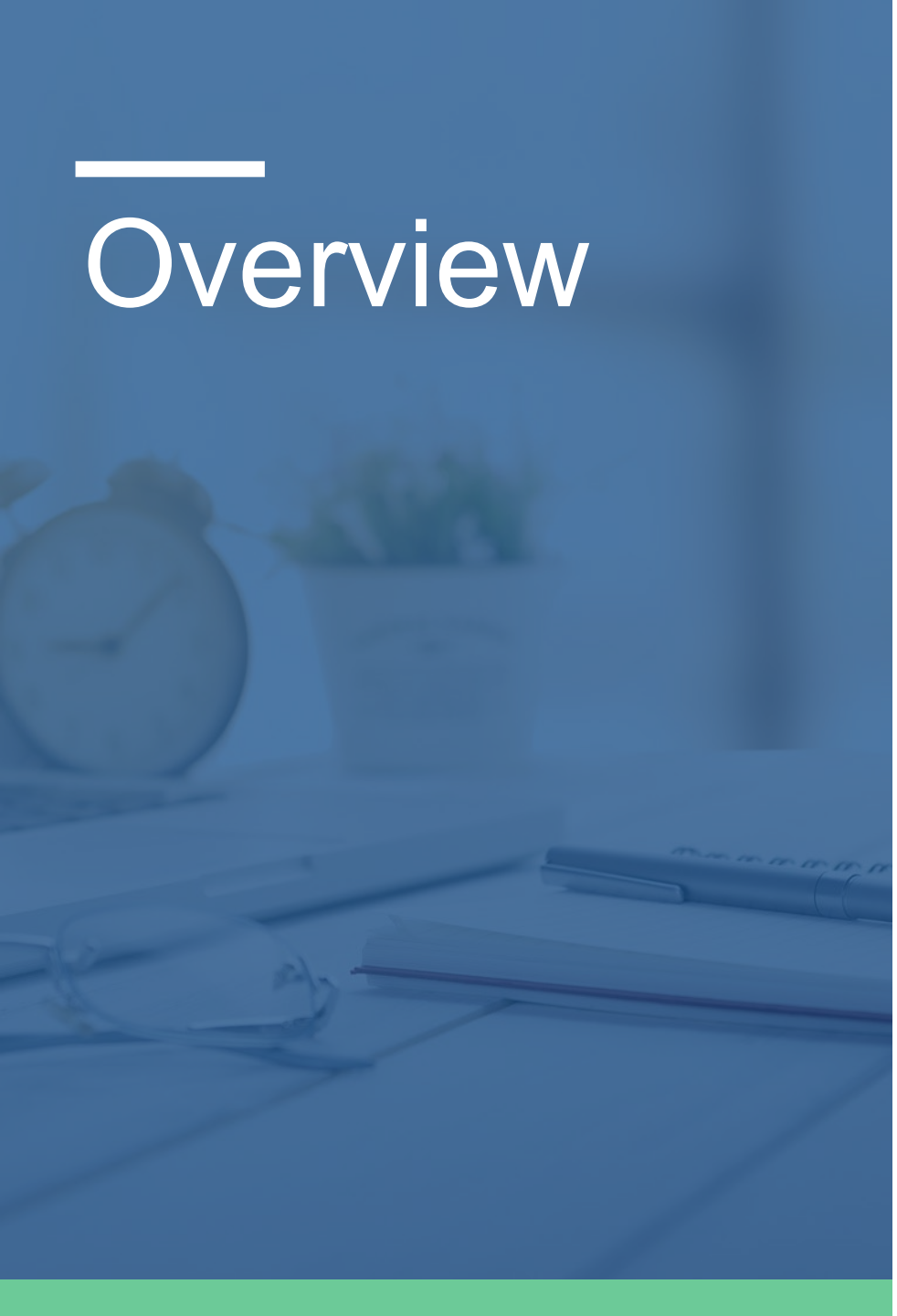
Overview



Overview of PFAS in Sediment

- Characteristics, Toxicity, Nature and Extent

Occurrence in Pacific Northwest

Site-Specific Risk Assessment

Ecotoxicity and Bioaccumulation

Summary/Closing Statements

Impact of These Data

The numbers and uptake factors derived in these experiments are essential to Site-specific risk assessment since they allow us to:

- Predict the uptake of PFAS to aquatic life
- Predict the concentrations exposed to wildlife and humans that eat aquatic life
- Not need to derive/measure these numbers at sites
- Predict risk without needing to collect/measure PFAS in animals

Data Gaps

- Understanding uptake and toxicity of FASAs
- Limited toxicological data for human health and ecological risk assessment
- Understanding and characterizing ambient PFAS
- Understanding and modelling the risk of PFAS in mixtures

Key Takeaways

- PFAS can bind to and remain in aquatic sediment
- It may be appropriate for some sites to include sediment PFAS
- Currently, there is sufficient information to conduct risk assessments for some PFAS in sediment

Points of Contact

Presenter

Jason Conder

jconder@geosyntec.com

Presenter

Zach Pandelides

Zach.Pandelides@Geosyntec.com